NASA / CR-2002-211667

General Aviation Interior Noise: Part III – Noise Control Measure Evaluation

James F. Unruh, and Paul D. Till
Southwest Research Institute, San Antonio, Texas

May 2002

The NASA STI Program Office ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results ... even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA / CR-2000-211667

General Aviation Interior Noise: Part III – Noise Control Measure Evaluation

James F. Unruh, and Paul D. Till
Southwest Research Institute, San Antonio, Texas

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Grant NAG1-2288

May 2002

ACKNOWLEDGMENTS

The work reported herein was conducted by Southwest Research Institute™ for NASA Langley Research Center under NASA Research Grant NAG-1-2288 entitled, “General Aviation Interior Noise Source Identification Technology Research,” NLPN 00-205.

The authors wish to acknowledge the contribution of the Cessna Aircraft Company, Single-Engine Division who supplied the Model 182E and Model 206 test aircraft and fully supported the flight and ground test programs for these aircraft. Special recognition is extended to Mr. Ted Farwell, who coordinated the Cessna contributions and for skillful piloting of the test aircraft. The loan of a three-bladed propeller for the Model 182F aircraft from McCauley Propeller Systems is also greatly appreciated.

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF FIGURES

Page

LIST OF TABLES

1. INTRODUCTION

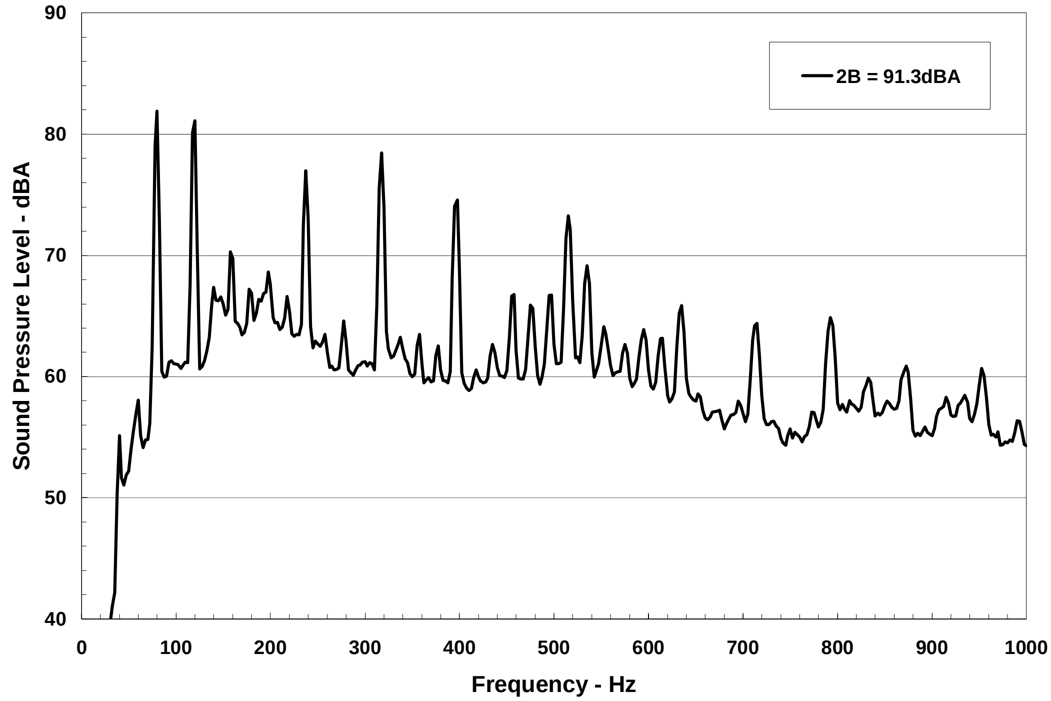
1.1 Background

Poor pilot communications with ground control personnel and passengers, and pilot and passenger fatigue during extended duration flights in single engine General Aviation aircraft is attributed to excessive interior noise and vibration. Typical cabin spectra for a single engine, two-bladed and three-bladed, propeller aircraft are given in Figure 1-1. The spectra were recorded in the same aircraft at identical power settings, namely, an engine speed of 2,400 rpm at 75% power cruise at an altitude of 5,000 ft. The two-bladed propeller noise spectrum is rich in harmonics of the fundamental engine rotational speed at 40 Hz with the dominant low frequency responses corresponding to harmonics of the fundamental propeller at 80 Hz and engine firing at 120 Hz, while the three-bladed propeller noise spectrum is dominated by the coincident harmonics of the propeller and engine firing at 120 Hz. Both spectra exhibit a mid-frequency response centered around 520 Hz consisting of several adjacent tones at 40 Hz spacing. The sources of these dominant tones are generally believed to be from airborne propeller, engine exhaust, and engine case radiation and/or from direct structure-borne vibration from engine excitation.

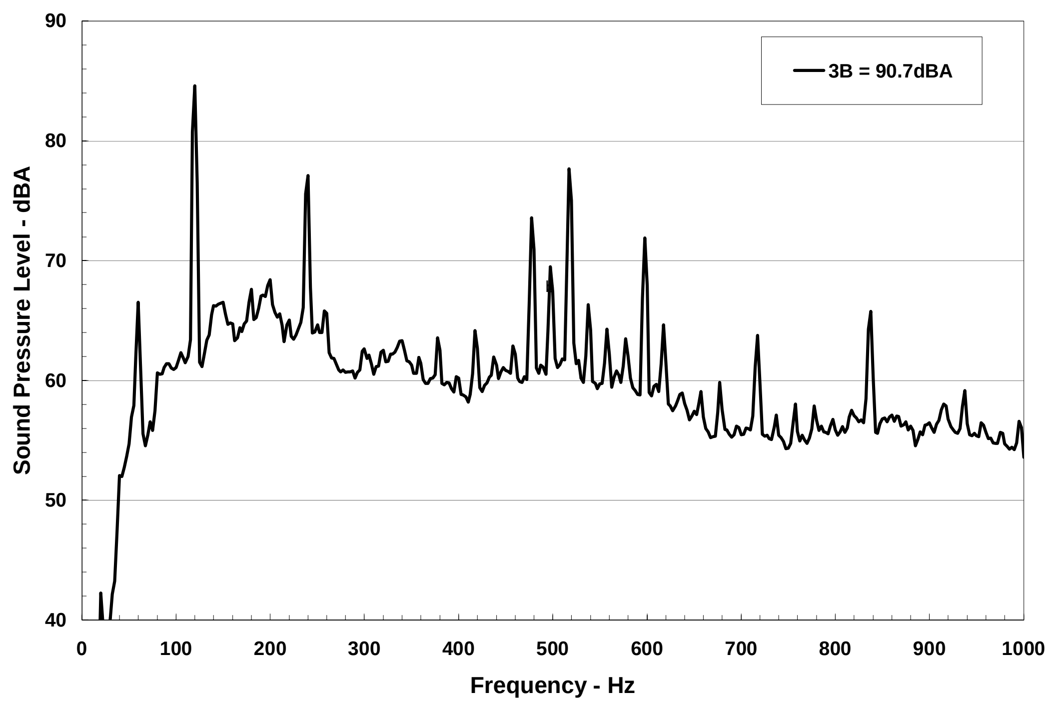
The work reported herein is an extension to the work accomplished under NASA Grant NAG-1-2091 on the development of noise/source/path identification techniques for single engine propeller driven General Aviation aircraft. The previous work developed a Conditioned Response Analysis (CRA) technique to identify potential noise sources that contributed to the dominating tonal responses within the aircraft cabin. The objective of the present effort was to improve and verify the findings of the CRA and develop and demonstrate noise control measures for single engine propeller driven General Aviation aircraft.

An improvement in the CRA procedures, including the generation of a normalized error parameter to guide the selection of simulation vectors, is described is Section 2. During the course of the present research effort, three single engine General Aviation aircraft were employed. In May 2000, the Cessna 182E aircraft, used in the previous noise source/path investigation, was flight tested with various applications of surface treatments to identify major paths of noise transmission into the aircraft. A summary of the results is given in Section 3. Thereafter, in October 2000, the Cessna 182E aircraft was flight tested at various propeller speed and engine power settings, employing both two- and three-bladed propellers, to determine to what extent aircraft operational effects could be used to reduce cabin noise levels. During the flight tests, the effects of tail cone and aft bulkhead treatments were evaluated and linear array measurements were recorded to determine the characteristics of the wave field within the cabin, also reported in Section 3. Thereafter, the Cessna 182E aircraft was returned from research to operational flight status and was no longer available for the program.

A Cessna Model 206 three bladed propeller single engine aircraft, void of all interior trim, was made available for the program. The bare cabin was believed to be a good test bed for development/demonstration of noise control treatments. Ground and flight tests were conducted on the Model 206 during March 2001 to identify panel resonant response, cabin acoustic wave



a) Two-Bladed Propeller



b) Three-Bladed Propeller

Figure 1.1 Typical Single Engine General Aviation Interior Noise Spectra.

characteristics, and cabin noise and vibration levels during normal cruise conditions, as reported in Section 4. Unfortunately, the Cessna Model 206 was removed from the program before noise control measures could be developed. At this point in the program, a Cessna Model 182F was leased from a private individual, which would allow interior removal and application and evaluation of various passive and active noise control measures. The Model 182F was equipped with a three-bladed propeller, supplied to the program by McCauley Propeller Systems, and underwent extensive ground and flight tests, as reported in Section 5.

Hundreds of noise and vibration spectra were recorded and analyzed during the various ground and flight tests conducted during the project. The authors have attempted to extract sample data from which general conclusions can be drawn as to the nature of the noise environment in single engine General Aviation aircraft and potential for noise control measure application. Several general observations and conclusions are summarized in Section 6. Detailed summaries of all data were transmitted to NASA Langley and were placed into a NASA General Aviation Database along with other research contributions from other organizations. Reference is made to this database throughout the report by the specific entries in the database contained within square brackets [*], as listed in Section 7.

2. IMPROVED CONDITION RESPONSE ANALYSIS

The Condition Response Analysis (CRA) conducted on the Cessna Model 182E single engine propeller driven aircraft, as reported in the Research Summary for NASA Grant NAG-1-2091 dated September 1999 [1], was revised to include error analyses and the simultaneous inclusion of both auxiliary pressure and accelerometer responses during the evaluation.

In the previous CRA analysis, the set of auxiliary accelerometers on the engine and engine mount structure were independently employed to predict the level of structure-borne noise transmission. The level of structure-borne noise transmission due to engine vibration was found to be quite low. Nevertheless, the corresponding acceleration responses at all other auxiliary locations were predicted based on the estimated level of structure-borne engine vibration transmission into the aircraft and these response levels were then removed from the in-flight response vector before the airborne transmission predictions were carried out. The airborne transmission predictions were carried out in two analysis sets. The one analysis set included all accelerometer responses on aircraft panels and lightweight structure, which were all the accelerometer responses not included in the initial structure-borne noise transmission evaluation. The second analysis set included all microphone responses, which consisted of several microphones external to the aircraft and one under the engine cowling adjacent to the firewall. The details of the analysis process are given in Reference [1].

The primary reason for separating the accelerometer and microphone responses in the previous CRA analyses was the large difference in magnitudes between the accelerometer responses in gravity units and the microphone responses in normalized pressures relative to the standard reference pressure of 2 x 10^{-5} Pascal. To elevate this problem, the accelerometer responses were scaled by the characteristic impedance of the radiation media as shown by the following expression:

$$\left(\frac{p_{rms}}{P_{ref}}\right) = \frac{1}{\omega}\left[\rho_0 c\left(\frac{g}{P_{ref}}\right)\right]\left(\frac{a_{rms}}{g}\right) \tag{2.1}$$

where, ω is the circular frequency, ρ_0 is the density of the media, c is the speed of sound, g is the acceleration due to gravity (9.8 m/sec), and P_{ref} is the reference pressure (2 x 10^{-5} Pascal).

The CRA procedure used to relate the ground test response data to the in-flight response data begins with determining the linear sum of ground test airframe response parameter vectors, which best fit the in-flight airframe response parameters measured during flight. Thus, we seek the vector $\{\alpha\}$, such that:

$$\{\tilde{a}^f\} = [A^G]\,\{\alpha\} \tag{2.2}$$

where,

$\{\tilde{a}^f\}$ – is to be a close approximation to $\{a^f\}$, the <u>in-flight</u> airframe response vector,

$[A^G]$ – is a matrix of selected $\{a^g\}$ response vectors (N x J),

and

$\{\alpha\}$ – the desired source simulation weight vector (J x 1).

This being the case, we may then estimate the in-flight structure-borne and airborne noise components from:

$$\{\tilde{\tilde{p}}\} = [P^G]\,\{\alpha\} \tag{2.3}$$

where,

$\{\tilde{\tilde{p}}\}$ – is an estimate of the in-flight response vector,

$[P^G]$ – is a matrix of the $\{p^g\}$ response vectors (N x J), consistent with $\{\alpha\}$ and

$\{\alpha\}$ – is the source simulation weight vector determined from the best fit to the in-flight structural response parameters.

The solution approach taken was to include all the ground simulation information in a single evaluation and to use a Moore-Penrose pseudo inverse of the over determined system of equations to obtain a solution.

$$\{\alpha_k\} = pinv\,[A^G]\,\{a^f\} \tag{2.4}$$

The extent to which the above formulation of CRA facilitates noise source/path identification for the Cessna Model 182E aircraft was evaluated using the ground test source simulation data sets consisting of airborne propeller (ABP), airborne exhaust (ABEX), airborne engine (ABE), structure-borne engine (SBE), and two additional structure-borne simulations via direct excitation of the right forward (SBRM) and left forward engine mounts (SBLM). The latter two simulations were not employed in the previous study; however, they were included in the present analysis for completeness. The above accelerometer response scaling was applied to the corresponding rows of Equation 2.2 before the pseudo inverse process. The normalized error for the fit process was based on the difference between the measured in-flight response vector, $\{a^f\}$, and the predicted response vector, $\{\tilde{\tilde{a}}^f\}$, normalized by the mean of the in-flight response vector.

A conditioned response analysis for selected tones for the Cessna Model 182E aircraft was carried out initially using all six simulation vectors, and the results are given in Table 2-1. For each of the tones analyzed, the in-flight measured sound pressure levels at four interior microphones AC1 through AC4 are given in the table under the heading of "In-Flight Levels." The predicted responses for these interior microphones are given in the adjacent column along with the contribution from each of the simulation vectors used in the analysis. The last two columns give the mean and standard deviation of the normalized error resulting from attempting to match the 27 auxiliary responses measured during the flight. The simulations for the 120 Hz first firing (1F) tone and the 480 Hz fourth firing and sixth propeller (4F-6P) harmonics appear to be worth noting. Results for the other tones are not encouraging, and further evaluation was carried out. Various combinations of the source simulations were used to reduce the normalized error while maintaining cabin levels similar to those measured in flight. The following conclusions were drawn from the optimum CRA solutions given in Table 2-2:

1. **80 Hz Fundamental Propeller Tone:** Clearly the distribution of higher noise levels in the aft of the aircraft (AC3 and AC4) could not be simulated with any combination of the simulation vectors generated during the CRA. The airborne propeller simulation vector resulted in the lowest normalized error (1.15), which indicates a very poor match. The conclusion is that the major noise source associated with the fundamental propeller was not properly simulated. The propeller wake tip vortex impingement on the fuselage may be the missing source.

2. **120 Hz Fundamental Engine Firing Tone:** This tone appears to be best simulated using only the airborne exhaust simulation source vector. While the predicted cabin noise levels are higher than measured, the general distribution is well represented. When the airborne engine simulation vector was coupled with the exhaust simulation vector, the normalized error was slightly reduced from 0.66 to 0.63; however, the predicted cabin levels were even higher.

3. **160 Hz Second Propeller Harmonic:** The best simulation for this tone is the airborne propeller source. The distribution of cabin noise levels appears to be reasonable, however, somewhat low. This indicates that propeller airborne noise is a contributor and there may possibly be a source missing which would improve the CRA procedure.

4. **240 Hz Second Firing and Third Propeller Harmonics:** The airborne propeller and exhaust simulation vectors provided the best fit for this spectral component. The predicted cabin levels were reasonable, and the normalized error was 0.47.

5. **400 Hz Fifth Propeller Harmonic:** No combination of available source simulations could be used to improve the high level of normalized error found for this tonal component. Thus, there may be an additional noise source responsible for this spectral component.

6. **480 Hz Fourth Firing and Sixth Propeller Harmonics:** A very good fit for this spectral component was achieved using all of the airborne simulation vectors, normalized error being 0.22. However, the addition of the structure-borne simulation vectors resulted in only a small decrease in the normalized error to 0.21 with negligible changes in the level of cabin noise transmission. It appears that the major contributor to this component is airborne engine case radiation.

Table 2.1 Conditioned Response Analysis Using All Simulation Vectors.

Tone	Cabin Microphone	In-Flight Levels	Predicted Response Levels							Error	
			ALL	ABP	ABEX	ABE	SBE	SBRM	SBLM	Mean	Stdev
80 1P	AC1	69.9	79.5	82.8	0	76.1	70.1	54.5	38.5	1.84	8.93
	AC2	70.4	77.5	80.9	0	76.7	71.6	54.1	56.4		
	AC3	83.3	77	78.8	0	68.9	67.7	53.8	58.9		
	AC4	82.6	73.2	76.3	0	68.7	72.5	58.5	59.6		
120 1F	AC1	80.4	88.5	0	88.4	93.9	78.9	70.6	53.8	0.56	4.46
	AC2	78.1	86.4	0	88.5	94	83.7	79.4	78.3		
	AC3	81.9	92	0	94	87.8	81.8	70.7	68.8		
	AC4	76	83.6	0	83.2	87.2	76.5	65.3	67.3		
160 2P	AC1	76.2	73.4	65.9	0	70.7	51.8	53.1	19.8	0.99	2.43
	AC2	82.8	74.8	71.1	0	62.1	46.1	64.4	35.3		
	AC3	81.1	75.1	73.9	0	71.6	48.6	61.8	47.3		
	AC4	79.5	77.9	75.5	0	64.7	48.5	65.7	42.4		
240 2F-3P	AC1	75.9	80.7	75.9	78	66	39.9	49.7	32	1.01	4.22
	AC2	69.5	79.6	73.4	70.5	61.7	39.1	46.5	59.2		
	AC3	85.6	81.3	84	74.6	58.4	43.1	35.9	52.6		
	AC4	75.4	86.4	84.7	73.8	57.1	49.4	52.2	57.3		
400 5P	AC1	79.4	69.6	63.2	0	69.1	40.8	48.2	32.6	1.12	4.61
	AC2	80.5	54	54.6	0	53.9	60	41	53.1		
	AC3	64.8	70.3	65.7	0	64.4	48	39.5	44.6		
	AC4	66.4	70.3	44	0	67.6	60.5	44.7	48.6		
480 4F-6P	AC1	82.8	77.1	70.9	52.8	76.2	55.3	51.3	46.9	0.21	0.83
	AC2	81.1	85	51.9	50.2	84.9	53.5	58.8	63.1		
	AC3	72.2	76.6	60.6	57.3	78.4	54.5	53.8	60.8		
	AC4	74.8	74.1	63.9	54.6	69.8	50.4	48.8	59.6		

Table 2.2 Conditioned Response Analysis Using Optimum Simulation Vectors.

Tone	Cabin Microphone	In-Flight Levels	Predicted Response Levels							Error	
			ALL	ABP	ABEX	ABE	SBE	SBRM	SBLM	Mean	Stdev
80 1P	AC1	69.9	78.8	78.8	0	0	0	0	0	1.15	9.47
	AC2	70.4	77.0	77.0	0	0	0	0	0		
	AC3	83.3	74.9	74.9	0	0	0	0	0		
	AC4	82.6	72.3	72.3	0	0	0	0	0		
120 1F	AC1	80.4	86.6	0	86.6	0	0	0	0	0.66	5.07
	AC2	78.1	86.7	0	86.7	0	0	0	0		
	AC3	81.9	92.2	0	92.2	0	0	0	0		
	AC4	76	81.4	0	81.4	0	0	0	0		
160 2P	AC1	76.2	68.2	68.2	0	0	0	0	0	0.60	2.90
	AC2	82.8	73.4	73.4	0	0	0	0	0		
	AC3	81.1	76.2	76.2	0	0	0	0	0		
	AC4	79.5	77.8	77.8	0	0	0	0	0		
240 2F-3P	AC1	75.9	77.1	74.7	0	66.6	0	0	0	0.47	5.43
	AC2	69.5	73.4	72.3	0	62.3	0	0	0		
	AC3	85.6	82.9	82.9	0	59.0	0	0	0		
	AC4	75.4	83.9	83.6	0	57.7	0	0	0		
400 5P	AC1	79.4	69.6	63.2	0	69.1	40.8	48.2	32.6	1.12	4.61
	AC2	80.5	54	54.6	0	53.9	60	41	53.1		
	AC3	64.8	70.3	65.7	0	64.4	48	39.5	44.6		
	AC4	66.4	70.3	44	0	67.6	60.5	44.7	48.6		
480 4F-6P	AC1	82.8	77.0	70.4	51.9	76.2	0	0	0	0.22	0.96
	AC2	81.1	84.9	51.5	49.3	84.9	0	0	0		
	AC3	72.2	76.7	60.1	56.4	78.4	0	0	0		
	AC4	74.8	73.6	63.4	53.7	69.8	0	0	0		

3. CESSNA MODEL 182E

The Cessna Model 182E was an unmodified single engine two-bladed propeller experimental aircraft equipped with a standard interior, as shown, fitted with a three-bladed propeller, in Figure 3-1. This aircraft was employed in the previous project to develop noise source/path identification techniques [1] and was used in two additional flight test programs, results from which are summarized below. The instrumentation layout used during the flight tests consisted of 9 microphones and 7 accelerometers located under the engine cowling and within the aircraft cabin, as listed in Table 3-1. The aircraft was nominally operated in the standard cruise condition at 75% power at a fixed engine speed of 2,400 rpm at an altitude of 5,000 feet, unless otherwise noted.

Figure 3.1 Cessna Model 182E Test Aircraft with Three-Bladed Propeller.

Table 3.1 Instrumentation Layout and Channel Assignment.

Channel	Type – Nomenclature	Description
1	Accelerometer – EC2	Engine lateral vibration
2	Accelerometer – EC12	Firewall normal acceleration – mid center
3	Microphone – EC14	Firewall sound pressure level – upper center
4	Microphone – AC1	Above pilot's control column
5	Microphone – AC2	Above co-pilot's control column
6	Microphone – AC3	Near right rear seat passenger's head
7	Microphone – AC4	Near left rear seat passenger's head
8	Microphone – AC20	Between pilot and co-pilot ear height
9	Microphone – AC21	Behind pilot's head
10	Microphone – AC22	Behind co-pilot's head
11	Accelerometer – CB1	On center of aft cabin bulkhead
12	Accelerometer – AC5	Instrument panel right side
13	Accelerometer – AC7	Windshield right side
14	Accelerometer – AC9	Pilot's side window center
15	Accelerometer – AC11	Right rear passenger's window center
16	Microphone – TC1	A/C Tail cone

3.1 Surface Treatment Evaluation

Various passive noise treatments were applied to the surfaces of the test aircraft in an attempt to identify the major noise source paths. The areas of the test aircraft, where application of noise absorption or noise blocking materials were used to identity paths of noise propagation, are listed in Table 3-2 along with the material used, namely, the configuration nomenclature, approximate area of coverage, and approximate weight of the material. Table 3-3 gives the make-up of the passive control materials. Twelve flight test configurations were flown with various combinations of applied materials, including a baseline configuration. A composite spectrum of the seven interior microphones recorded during the flight test of the baseline configuration is given in Figure 3-2. The corresponding noise levels are listed in Table 3-4. The highest noise levels are in the forward cabin at AC1 and AC2. Of particular concern are the major tones at the blade passage frequency of 80 Hz and firing frequency of 120 Hz and their harmonics.

Table 3.2 Schedule of Treatment Locations and Applicable Materials.

Location to be Treated	Config.	Area (ft^2)	Weight (lbs)	Applicable Materials	Usage
Under Cowling: UCT					
Firewall	C2	4.6	4.6	WB10-PSA	Add Transmission Loss & Absorption
Muffler Wrap	MW	3.0	3.25	WB10 + Fiberfax	Add Transmission Loss
Cowling Surface	C3	**		E-100SM-PSA	Add Absorption
In Cabin:					
Front Side Windows (2)	FW1	2.8R 2.8L	2.91R 2.80L	1) WB10-PSA	Add Transmission Loss
	FW2	2.8R 2.8L	2.97R 2.70L	2) R104-10CM-25PSA	Increase Transmission Loss
Rear Side Windows (2)	RW1	1.75R 1.75L	1.80R 1.86L	1) WB10-PSA	Add Transmission Loss
	RW2	1.75R 1.75L	1.70R 1.88L	2) R104-10CM-25PSA	Increase Transmission Loss
Instrument Panel	IPS	4.5	4.5	WB10- PSA	Add Transmission Loss
Windshield	WS1	11.5	11.65	1) WB10-PSA	Add Transmission Loss
	WS2	11.5	11.38	2) R104-10CM-25PSA	Increase Transmission Loss

**80% Coverage of both top and bottom of Cowling with 1-inch absorption material – estimate from photographs.

Table 3.3 Description of Materials.

Material	Weight/Area (lbs/ft^2)	Description
WB10	1.0	Loaded vinyl with and without PSA
E-100SM-PSA	0.17	1-inch absorbing foam with 1 mil aluminized polyester surface + PSA
R104-10CM-25PSA	1.04	1.0 lb/ft^2 loaded vinyl with 0.25” decoupling foam + PSA

PSA – Pressure Sensitive Adhesive

Table 3.4 Baseline Interior Microphone Levels.

Microphone	Un-Weighted	A-Weighted
AC1	107.2	93.0
AC2	105.4	92.6
AC3	108.4	89.3
AC4	109.7	91.0
AC20	107.4	90.1
AC21	107.8	90.5
AC22	107.1	89.7

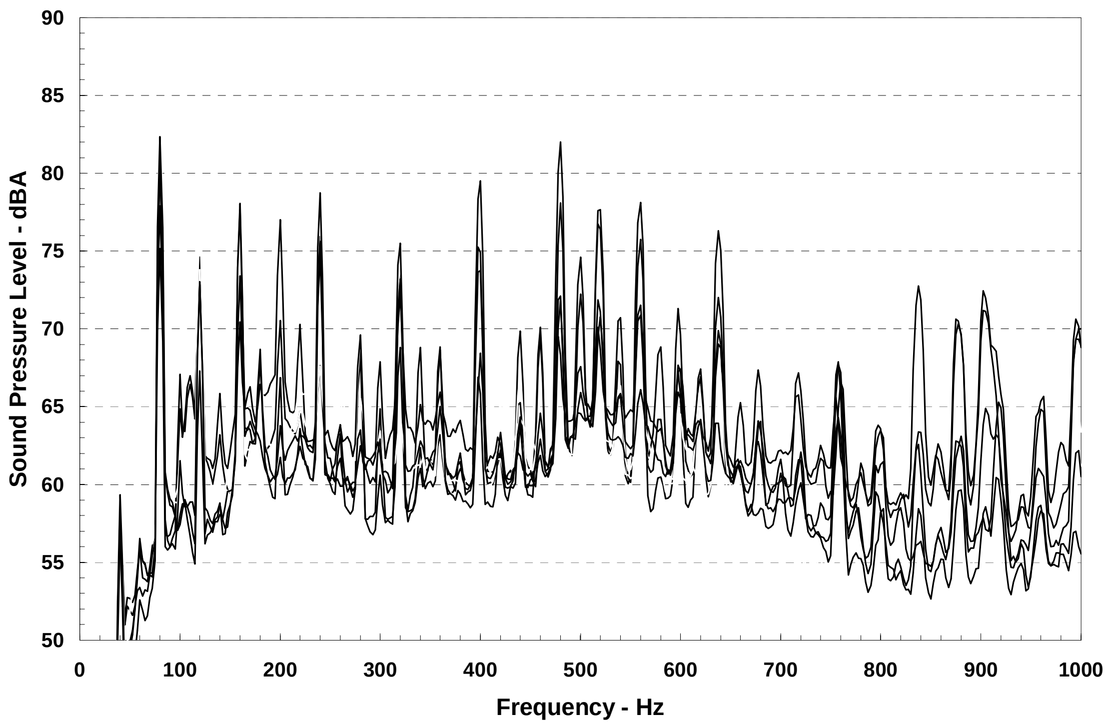


Figure 3.2 Interior Microphone Spectra: Baseline Aircraft @ 2,400 rpm, 75% Power Cruise.

Repeated data runs were made with the under cowling treatment to establish flight-to-flight repeatability in the measurements. It was found that repeatability to within 1.5 dB was achieved for all but the fundamental firing tone at 120 Hz, which exhibited a 4 dB variation between flights. Details on the effectiveness of the various noise control treatments on cabin noise reduction are given in Reference [2]. The limited areas where passive treatment appears to warrant further evaluation are discussed below.

3.1.1 Cabin Window Treatment

The extent of the cabin window treatment is shown in Figure 3-3. The instrumentation panel is also shown in this figure. Simultaneous coverage of the windshield and side

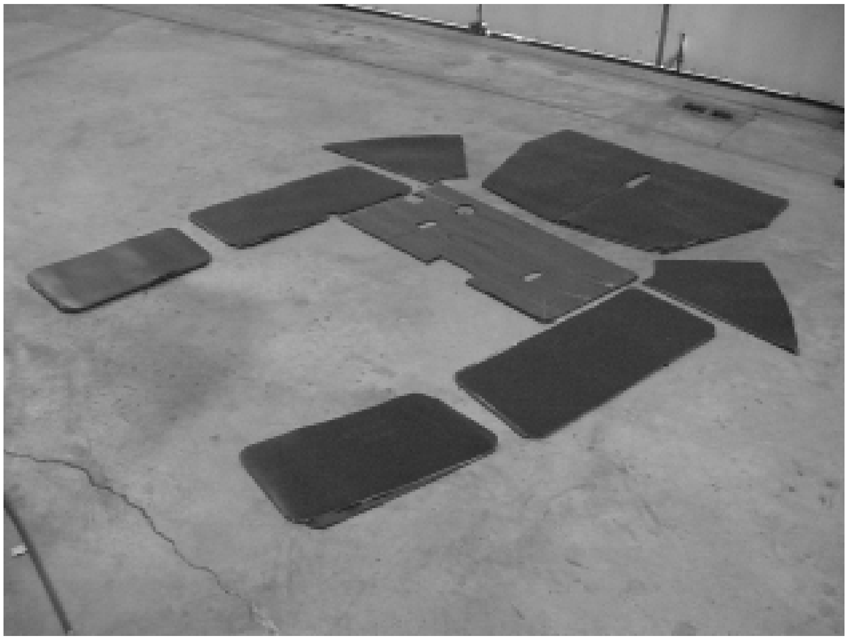


Figure 3.3 Interior Window Treatment.

windows of the cabin could not be accomplished due to safety issues associated with flying the aircraft totally blind. There appears to be some promise that treatment of the windshield will lower the average cabin levels for the 400 Hz tone, as shown in Figure 3-4. Likewise, the tone at 480 Hz appears to be sensitive to nearly all the passive treatments, as shown in Figure 3-5. As one should expect, passive treatment appears to be more effective for higher frequency control. The only exception being the under cowling treatment discussed below.

3.1.2 Under Cowling Treatment

The aircraft Under Cowling Treatment (UCT) consisting of: (1) 4.5 sq. ft. (4.5 lbs) of firewall blocking mass, (2) 1-inch thick absorber on 80% of the upper and lower cowling surface, and (3) Muffler Wrap (MW) 3 sq. ft. (3.25 lbs) blocking mass with fiberfax. Flight tests were conducted for the baseline aircraft, the full UTC and with the UTC minus the MW (UCT-MW). The under the cowling microphone (EC14) was used as a reference source indicator to compute what is defined as Firewall Noise Reduction (FNR) at the various interior microphone locations. Firewall Noise Reduction is the difference in noise levels between the under cowling microphone and the cabin microphone of interest at each of the tonal frequencies of interest.

Firewall noise reduction at the pilot's microphone (AC1) and co-pilot's microphone (AC2) positions are given in Figure 3-6. The data shows the Under Cowling Treatment to provide 8 to 13 dB(A) noise reduction at the fundamental blade passage frequency of 80 Hz. These levels were reduced to 6 dB(A) when the muffler wrap was removed. At the exhaust fundamental of 120 Hz, the Under Cowling Treatment showed a 5-6 dB(A) reduction in cabin noise levels; however, when the muffler wrap was removed, the levels returned to that of the baseline. At the propeller 2nd harmonic of 160 Hz and the combination 3P - 2F tone of 240 Hz, the noise reduction improved slightly when the muffler wrap was removed. It is to be noted that

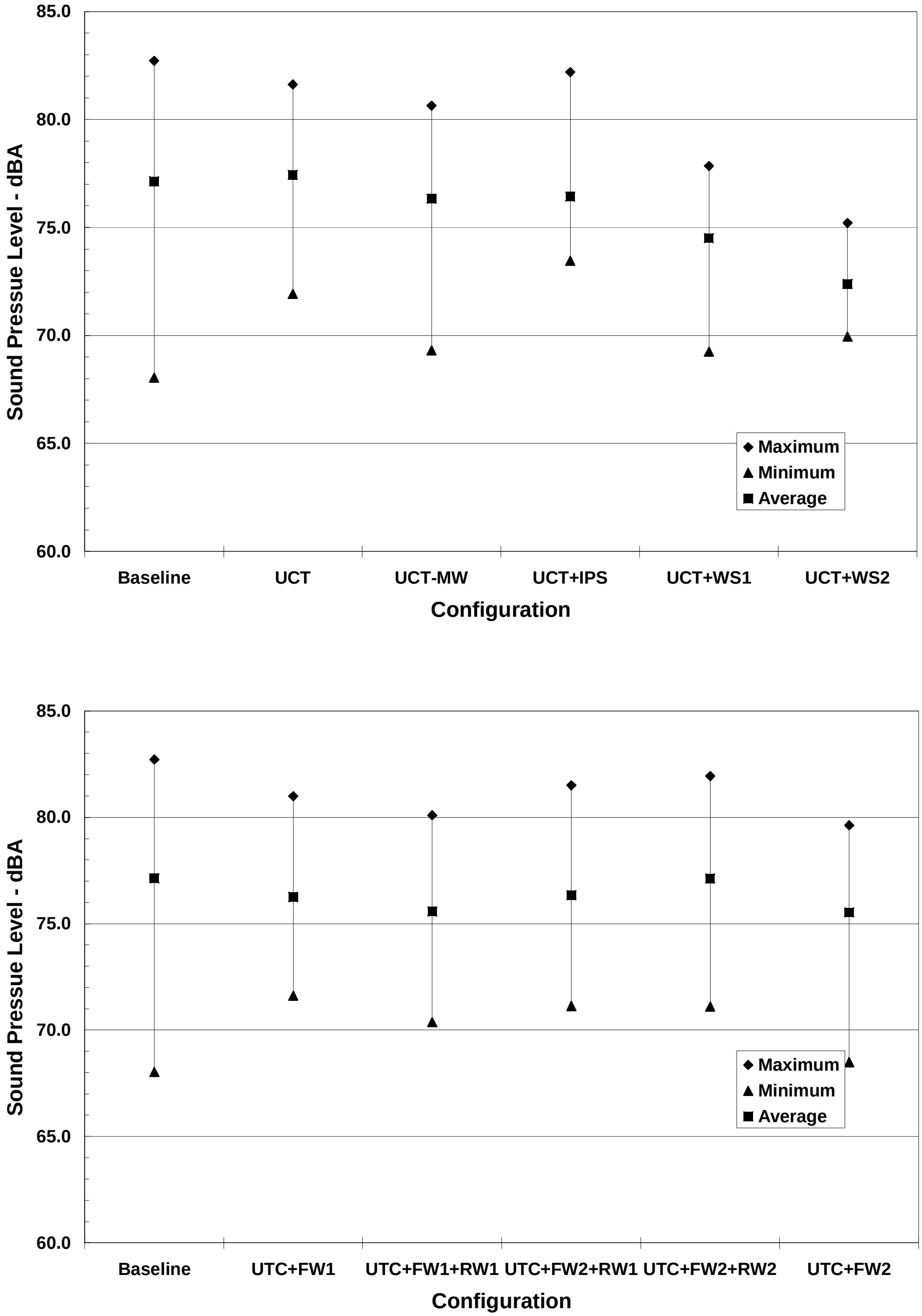


Figure 3.4 Effect of Treatment Configuration on Cabin 400 Hz – 5P Tone Level.

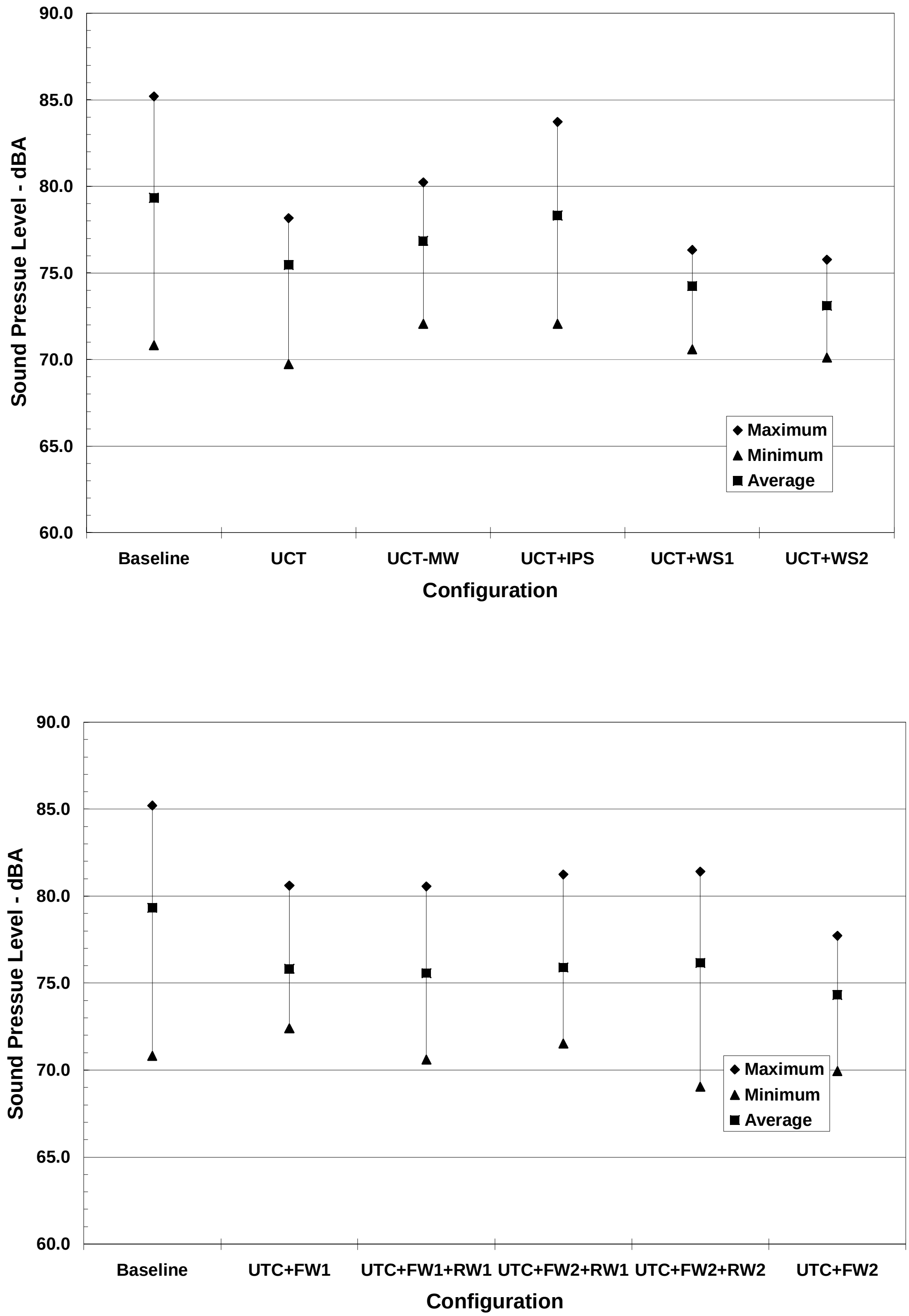
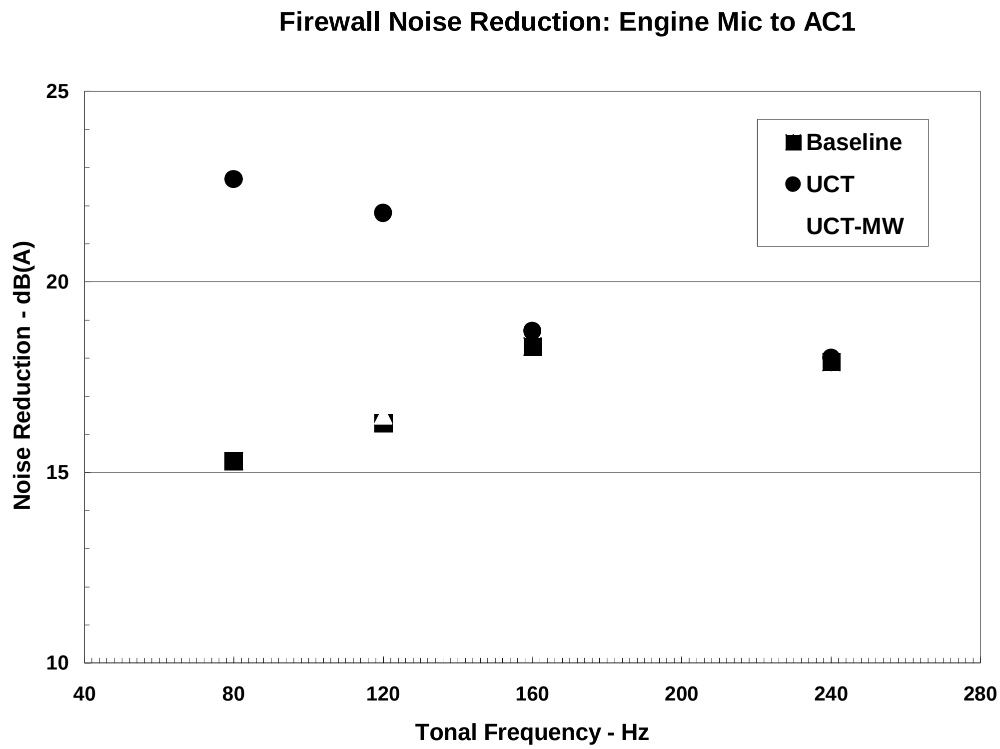


Figure 3.5 Effect of Treatment Configuration on Cabin 480 Hz – 4F-6P Tone Level.



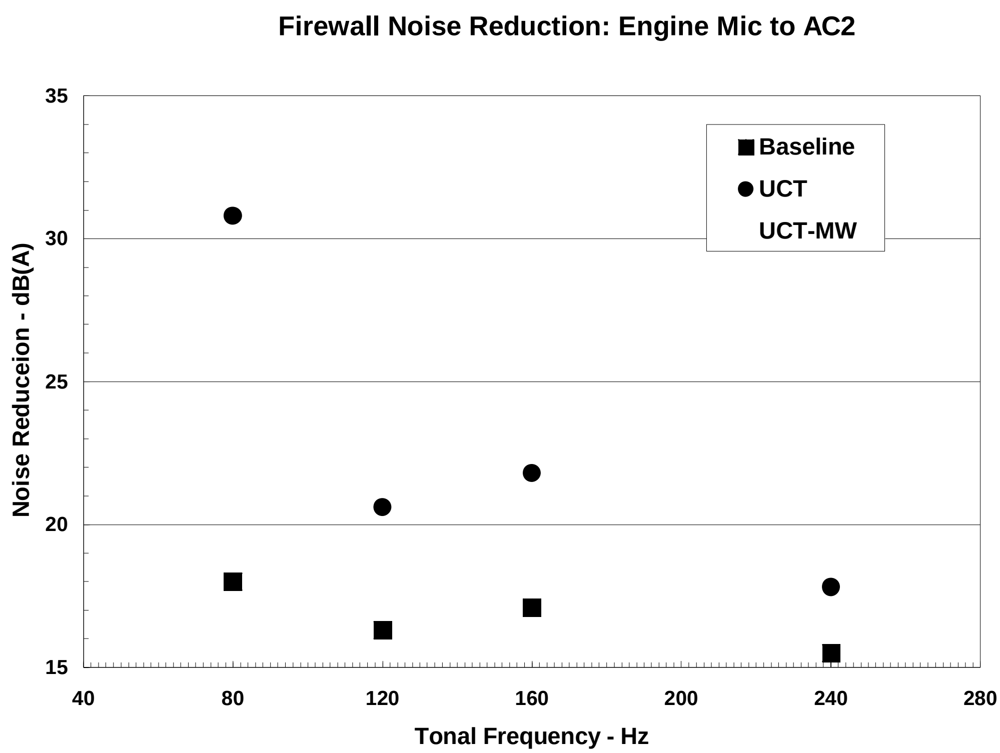


Figure 3.6 Firewall Noise Reduction.

the change in the reference microphone EC14 between data runs was less than 1.0 dB and, thus, small compared to the changes in noise reduction. Noise reductions at the rear passenger locations were not as pronounced as in the forward cabin. In general, it appears that the Under Cowling Treatment was most effective in the forward cabin and a viable noise control measure [58].

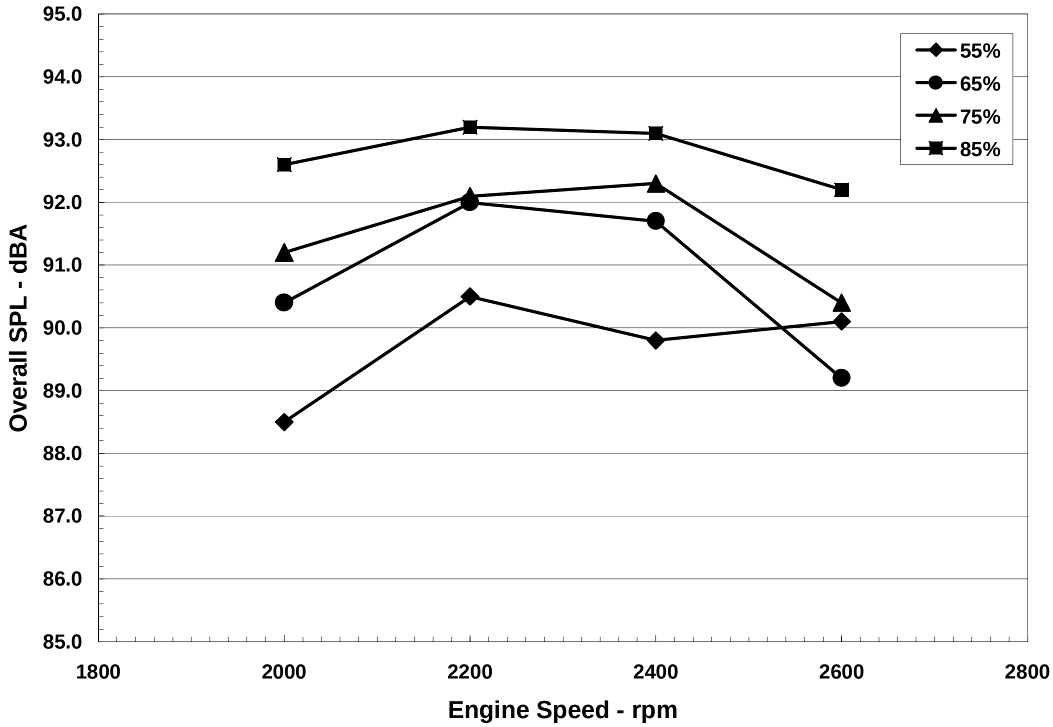
3.2 Aircraft Configuration and Operational Effects

To evaluate the effect of engine speed and power setting on cabin noise levels, the Cessna 182E was flown at an altitude of 5,000 feet at engine speeds of 2,000 rpm, 2,200 rpm, 2,400 rpm, and 2,600 rpm at power settings of 55%, 65%, 75%, and 85%, respectively, of maximum engine power. The speed and power matrix was flown for both the two-bladed and three-bladed propeller configurations to determine the effect of blade loading on the cabin noise levels [34]. Overall, sound pressure levels, out to 1,000 Hz, recorded at the pilot location AC1 and co-pilot location AC2 during the power matrix evaluation for both the two- and three-bladed propeller configurations are given in Figures 3-7 and 3-8, respectively. In general, the propeller cabin noise signatures increased with increasing engine power. For the two-bladed propeller configuration, it appears that increasing engine speed from 2,400 rpm to 2,600 rpm can be used to decrease the forward cabin noise levels by approximately 2 dB at the higher power settings. The three-bladed propeller exhibited an engine speed tuning effect with marked increases in cabin noise levels at 2,200 rpm for a couple of the engine power settings.

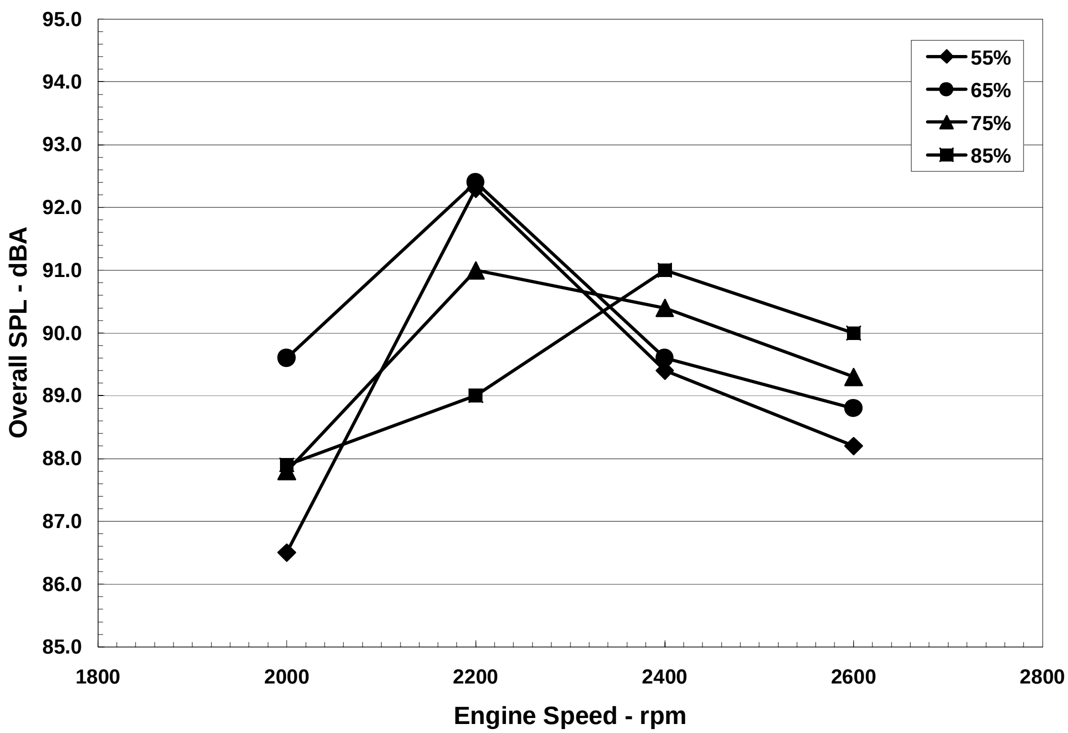
For the same power setting, the two-bladed propeller should have a higher per blade loading than the three-bladed propeller and, therefore, should produce higher noise levels. The difference in cabin noise levels between the two-bladed propeller and three-bladed propeller at each of the power and speed matrix test points were computed and are listed in Table 3-5. The difference in under cowling noise levels given by the data listed under EC14 can be used to indicate the expected differences due to engine noise, which appears to be small compared to several of the cabin noise level differences. There appears to be several engine power and speed points where significant noise reduction was achieved using the three-bladed propeller. The most noted difference in the use of a three-bladed propeller is the reduced number of distinct tones in the spectrum, which can be significant if narrow band noise control measures are required for noise reduction.

3.3 Tail Cone and Aft Bulkhead Treatments

The tail cone area of the aircraft represents a rather large volume that could possibly be used for noise control purposes or act as a noise source due to its large surface area on which propeller wake impingement may provide excitation. The bulkhead separating the cabin from the tail cone is a very lightweight molded Kydex® panel (see Figure 3-9) affording little in the way of transmission loss between the two volumes. An evaluation was carried out to determine if the tail cone volume was an active member in the generation or suppression of noise in the cabin area [35]. The aircraft tail cone was fitted with 8-inch deep wedges for a depth of approximately 36 inches to reduce reflections or sources from this area of the aircraft that may propagate energy into the aircraft cabin area, see Figure 3-10. The configuration was denoted as "TC Wedges."

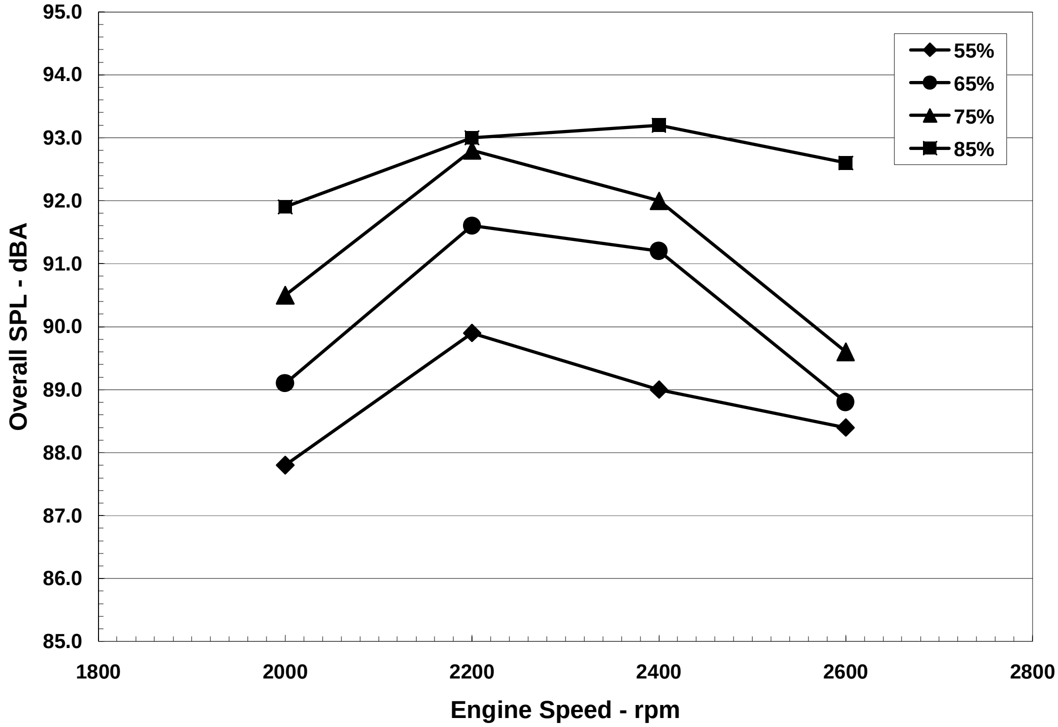


a) Two-Bladed Propeller

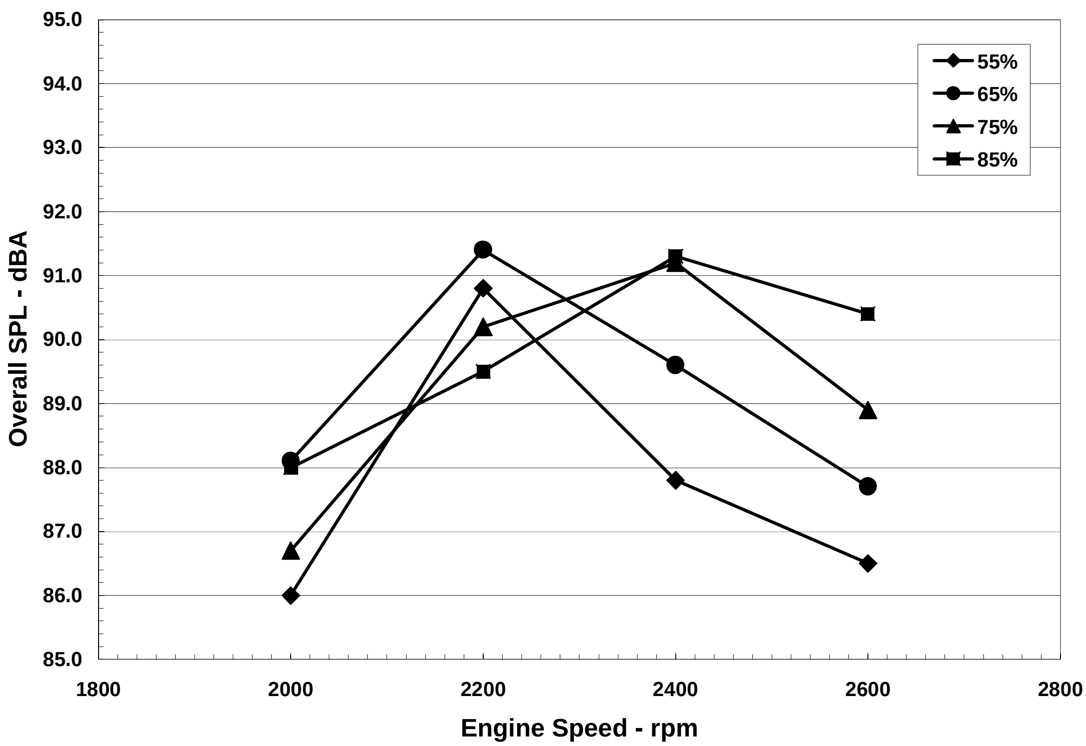


b) Three-Bladed Propeller

Figure 3.7 Engine Speed and Power Setting Effects on Pilot Microphone AC1.



a) Two-Bladed Propeller



b) Three-Bladed Propeller

Figure 3.8 Engine Speed and Power Setting Effects on Co-Pilot Microphone AC2.

Table 3.5 Overall SPL Difference: Two-Bladed Minus Three-Bladed Propeller.

AC1	Engine Power				AC2	Engine Power			
Speed	55%	65%	75%	85%	Speed	55%	65%	75%	85%
2000	2.0	0.8	3.4	4.7	2000	1.8	1.0	3.8	3.9
2200	-1.8	-0.4	1.1	4.2	2200	-0.9	0.2	2.6	3.5
2400	0.4	2.1	1.9	2.1	2400	1.2	1.6	0.8	1.9
2600	1.9	0.4	1.1	2.2	2600	1.9	1.1	0.7	2.2
AC3					AC4				
Speed	55%	65%	75%	85%	Speed	55%	65%	75%	85%
2000	-0.6	0.9	0.7	0.5	2000	0.5	1.7	3.8	2.8
2200	-1.8	1.2	1.2	0.5	2200	-2.2	0.5	3.2	2.2
2400	1.5	1.3	2.7	1.3	2400	2.9	3.7	3.5	3.2
2600	2.7	0.5	0.1	0.3	2600	3.7	2.7	0.7	2.6
AC20					AC21				
Speed	55%	65%	75%	85%	Speed	55%	65%	75%	85%
2000	1.0	0.9	2.1	2.1	2000	1.1	1.4	3.4	2.5
2200	-2.4	-1.5	1.1	1.2	2200	-1.2	-0.3	2.4	1.9
2400	1.1	1.2	0.6	1.5	2400	2.8	3.5	3.1	3.8
2600	2.3	0.5	0.1	0.3	2600	3.5	1.3	0.0	1.7
AC22					EC14				
Speed	55%	65%	75%	85%	Speed	55%	65%	75%	85%
2000	0.2	1.6	1.6	2.5	2000	-1.2	-1.2	-1.4	-1.2
2200	-1.4	-0.2	-0.1	-0.1	2200	-0.5	-0.5	-0.6	-0.1
2400	2.0	1.8	1.3	1.9	2400	-0.6	-0.7	-0.9	-0.6
2600	3.3	-0.2	1.1	0.9	2600	-0.6	-0.5	-0.8	-0.9

Flight tests were conducted at the standard cruise condition of 2,400 rpm and 75% power and noise levels recorded at the standard microphone locations. The lightweight bulkhead was then replaced with a ¾-inch thick medium density fiberboard (MDF) to greatly increase the transmission loss at the aft cabin location, denoted as "MDF Blkd," and the flight test repeated. This configuration was employed to maximize any effects of standing waves within the cabin. Data were also recorded for the standard Kydex® trim panel and denoted as "Standard." Measurements were taken for both the two-bladed and three-bladed propeller configurations. A comparison of the overall sound pressure levels within the cabin and tail cone areas are summarized in Table 3-6. Clearly, there is no difference in cabin noise levels between the three configurations for either propeller configuration. The difference in cabin noise levels between the two- and three-bladed configurations is clearly seen. The tail cone noise level (TC1) does not appear to be as sensitive to the change in propeller configuration.

3.4 Linear Array Measurements

The purpose of this effort was to evaluate the acoustic environment of the aircraft interior and characterize the environment as modal standing waves or free-field traveling waves within certain frequency ranges. The array used for this exercise consisted of 14 microphones spaced

Figure 3.9 Standard Aft Bulkhead.

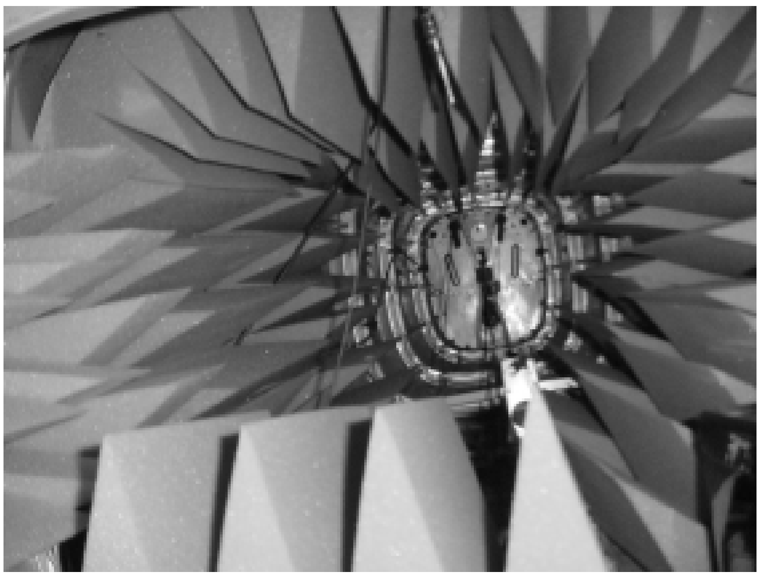


Figure 3.10 Tail Cone Fitted with Foam Wedges.

Table 3.6 Summary of Tail Cone and Aft Bulkhead Treatments.

Microphone	Overall Sound Pressure Level - dBA					
	Two Bladed Propeller			Three Bladed Propeller		
	Standard	TC Wedges	MDF Blkd	Standard	TC Wedges	MDF Blkd
AC1	92.3	91.9	92.2	90.4	90.9	90.5
AC2	92	92.3	92.2	91.2	91.5	91.3
AC3	89.6	88.8	88.8	86.9	86.4	86.5
AC4	92.1	92.1	91.6	88.6	88.4	88.5
AC20	90.4	90.3	90.3	89.8	90.2	89.5
AC21	91.6	91.9	91.5	88.5	88.7	88.4
AC22	90.2	90.6	89.8	88.9	89.3	88.7
TC1	97.2	90	88.2	96.5	N/A	88.2

six inches apart, aligned along the centerline of the aircraft. During flight, measurements were conducted with the forward most microphone in the array placed at the center of the instrument panel shroud, two inches above the edge. Microphones AC1 and AC2 were used as stationary reference microphones. The data was processed using reference microphone AC1 to determine the relative phase of the array microphones. Data was collected for the following three cabin conditions, for both the two-bladed and three-bladed propellers, namely, baseline, tail cone treatment with wedges, and MDF partition installed. Detailed results were generated in terms of sound pressure level and sound pressure phase distribution along the length of the cabin at 80, 120, 160, and 240 Hz for the two-bladed propeller configuration, and 120 and 240 Hz for the three-bladed propeller configuration [48]. A brief summary of the results is given below.

Results from the three test configurations were very consistent at any of the blade passage or engine firing frequencies. This confirms the passive effect of the tail cone and aft bulkhead on overall sound pressure levels within the cabin. Array results for the two-bladed propeller configuration with the baseline standard interior are shown in Figures 3-11 through 3-14. At 80 Hz, see Figure 3-11, a dip is observed in the sound pressure level in the forward cabin. This sound pressure level dip corresponds to a phase shift. After this phase shift occurs, the phase distribution becomes linear with a positive slope progressing into the middle and aft cabin having the characteristics of a traveling wave. At 120 Hz, the sound pressure level is rather uniform with a slight increase along the cabin and the phase trend is also linear. The sound pressure level distribution at 160 Hz also exhibits traveling wave characteristics, however, not as pronounced as for the lower frequency tones. The characteristics of the 240 Hz tone are much less obvious. Results for the three-bladed propeller, for the 120 Hz and 240 Hz tones, are given in Figures 3-15 and 3-16. The 120 Hz tone displays the linear phase trend typical of a traveling wave while the 240 Hz tone is similar to the two-bladed propeller being much less definitive. However, at 240 Hz, both propeller configurations initially appear as traveling waves. In general, it appears that the primary noise source is radiating from the forward cabin and propagating as a traveling wave. The drop-in sound pressure level in the forward cabin for the 80 Hz propeller tone may be due to phase interference from a secondary source, such as propeller wake impingement.

3.5 High Frequency Tone Evaluation

A high frequency tone appears in the cabin spectra of the Cessna 182E for a majority of the engine speed and power settings evaluated during the October flight tests [45]. The tone frequency ranges from 827.5 Hz to 910 Hz and is most dominant on the pilot side of the aircraft (AC1, AC4, and AC21). The high frequency tone is clearly seen in the spectra shown in Figure 3-2 for the two-bladed propeller aircraft. The high frequency tone is also present in the three-bladed propeller aircraft as can be seen in Figure 1-1b. At the aircraft standard engine speed and power settings, the tone was not as clear as for other flight configurations. The tone levels and response frequencies do not correlate with engine speed; however, the frequency of the tone appears to correlate well with aircraft speed, as is shown by the data in Figure 3-17. This data indicates the tone may be generated from a seal leak or aerodynamic disturbance, such as vortex shedding.

3.6 Cabin Active Noise Control Survey

Frequency response functions between nine potential speaker control source locations within the Cessna Model 182E aircraft cabin and the seven potential error microphone locations used during the flight tests were generated to assist in an Active Noise Control (ANC) evaluation of the aircraft [39]. A slow sine sweep (approximately 0.73 octave/minute) input in the frequency range from 40 to 500 Hz was used to drive the speaker to excite the cabin. The speaker cavity pressure was used as a measure of the source strength and, thus, was the reference input for all the frequency response functions. The drive speaker was located at nine different locations within the cabin as documented by photographs. The corresponding frequency response functions, displayed as real and imaginary, and magnitude and phase spectra were placed into the NASA General Aviation Database [39].

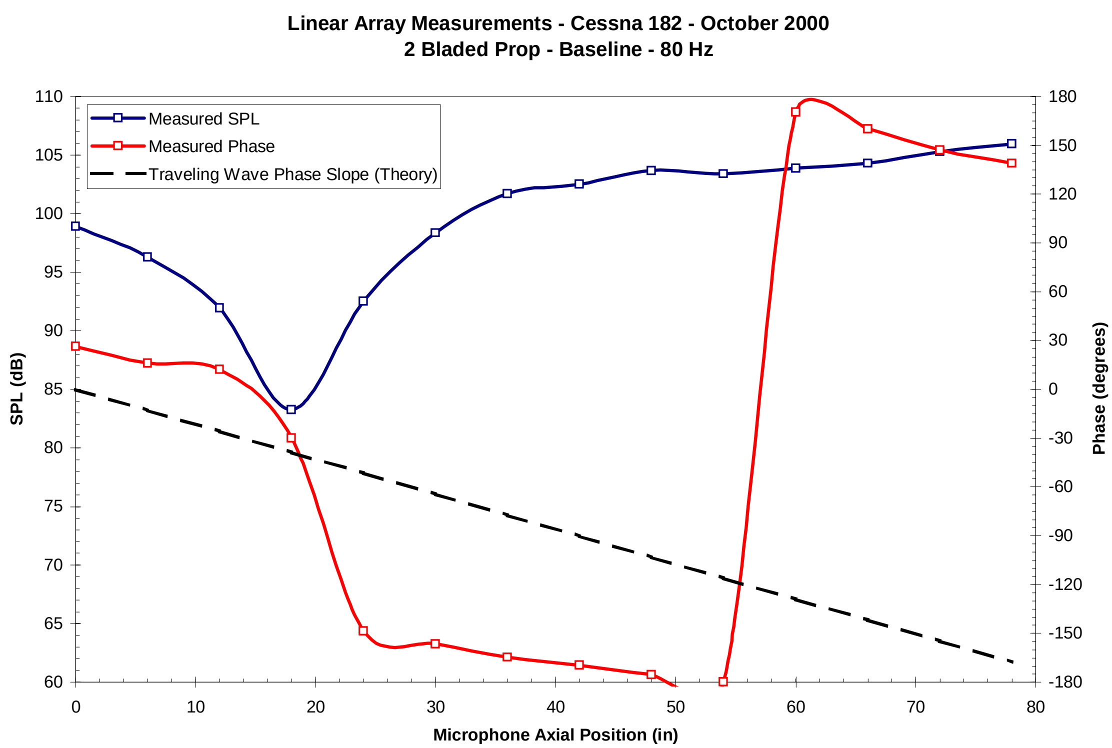


Figure 3.11 Array Results for Two-Bladed Propeller – Baseline – 80 Hz.

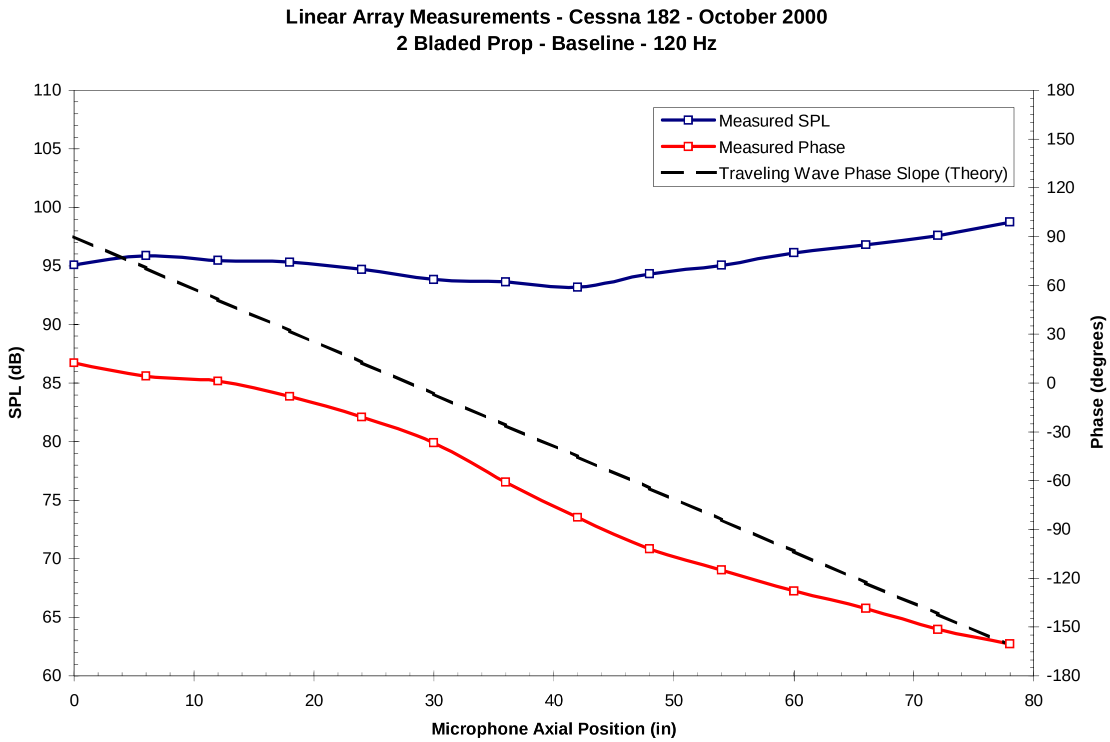


Figure 3.12 Array Results for Two-Bladed Propeller – Baseline – 120 Hz.

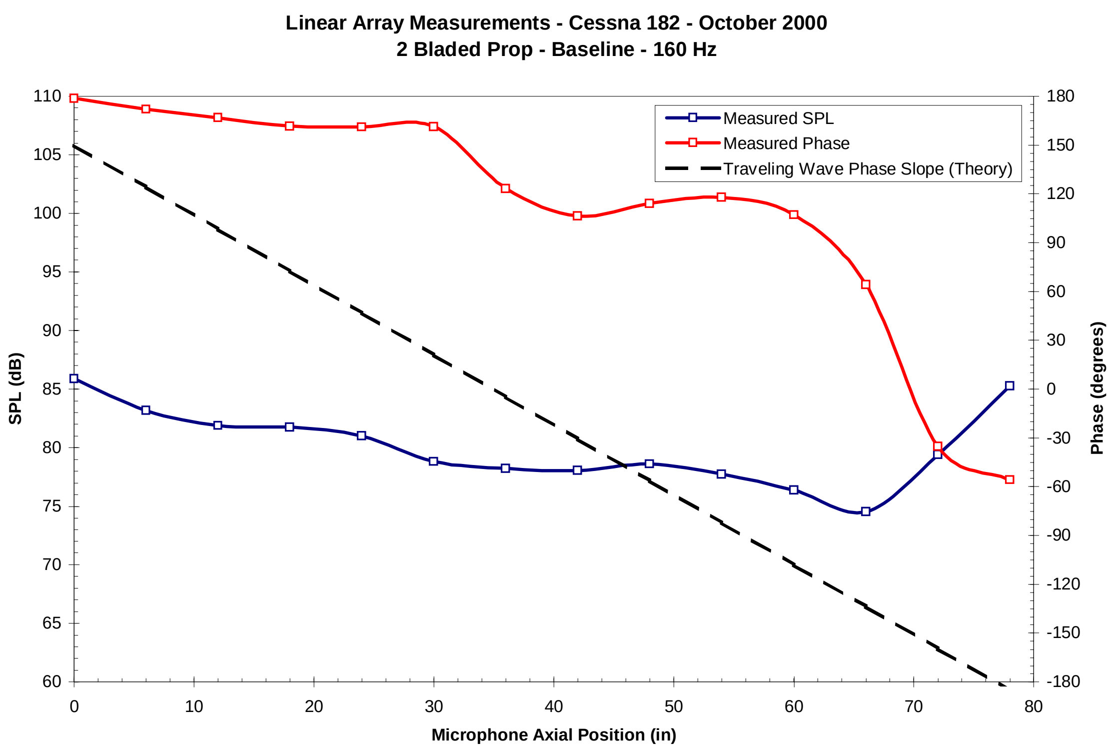


Figure 3.13 Array Results for Two-Bladed Propeller – Baseline – 160 Hz.

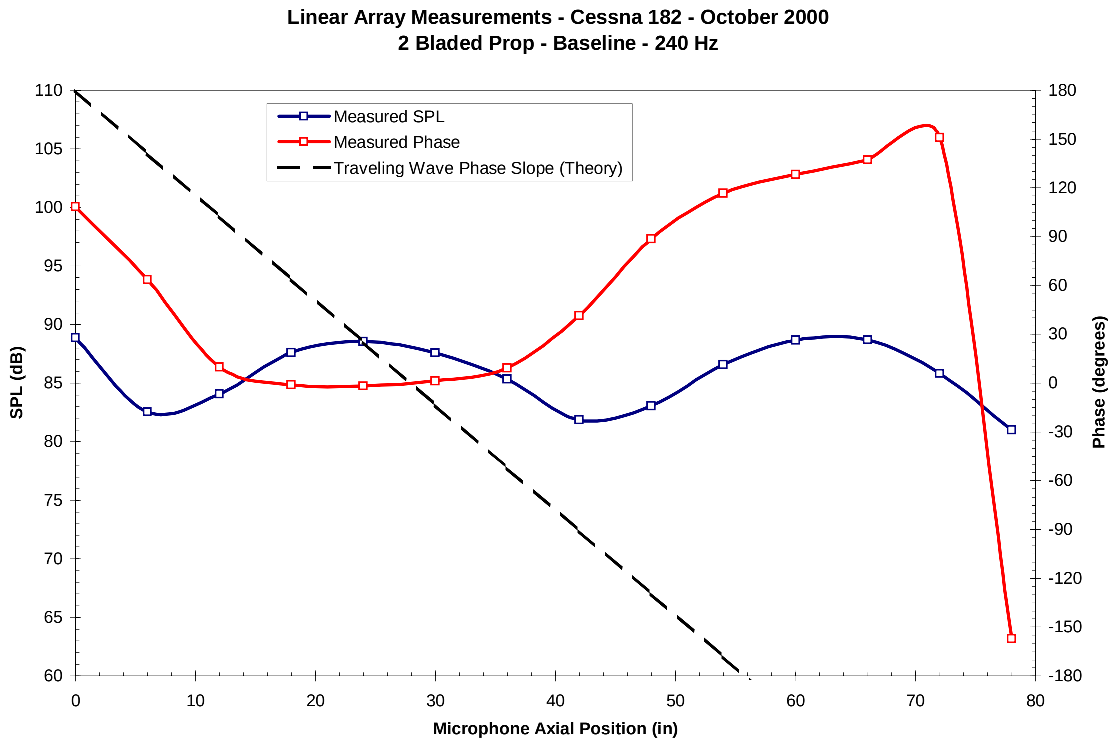


Figure 3.14. Array Results for Two-Bladed Propeller – Baseline – 240 Hz.

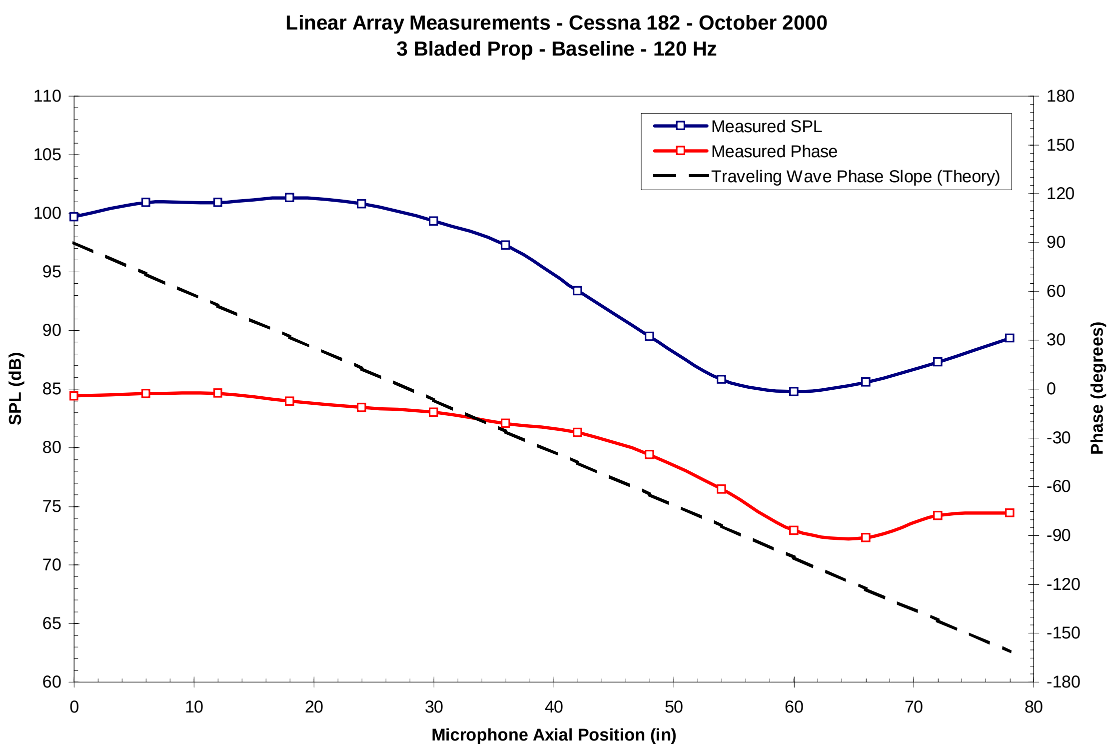


Figure 3.15 Array Results for Three-Bladed Propeller – Baseline – 120 Hz.

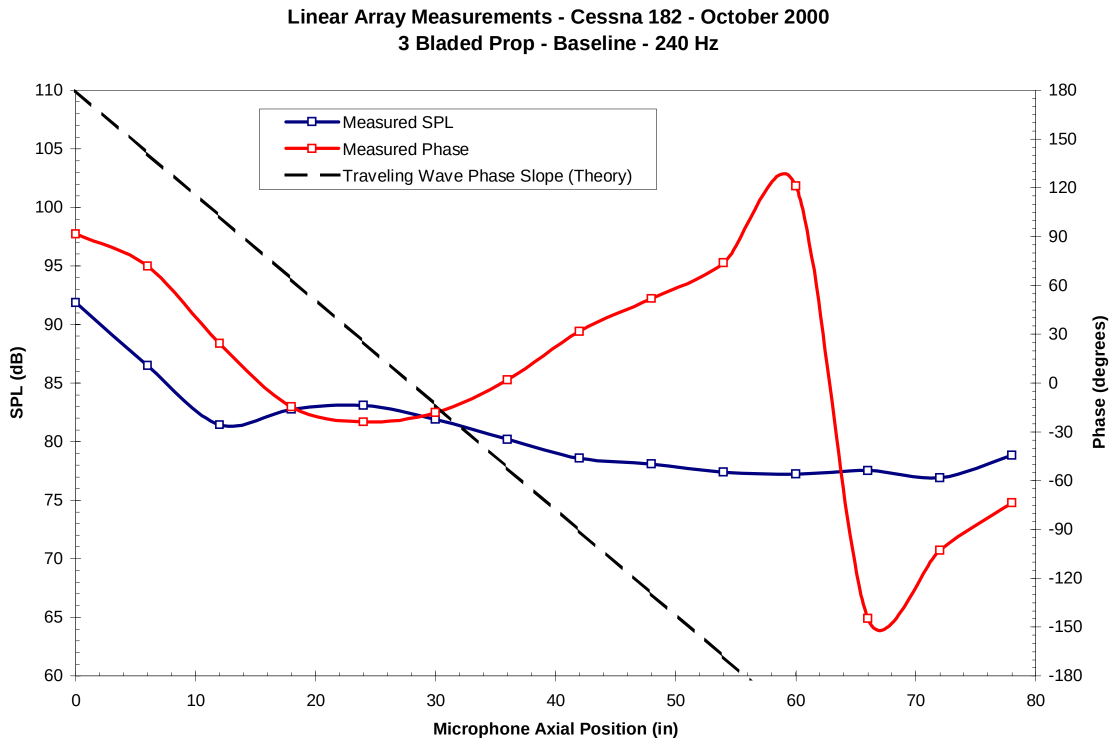


Figure 3.16. Array Results for Three-Bladed Propeller – Baseline – 240 Hz.

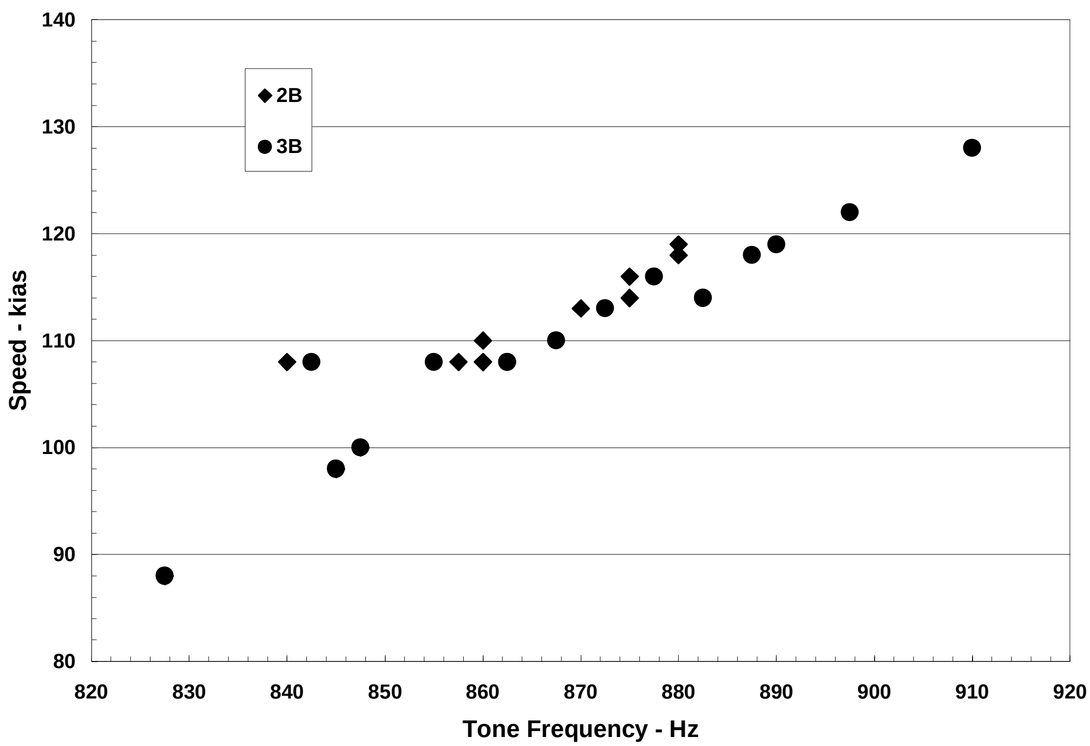


Figure 3.17 High Frequency Tone Correlation.

4. CESSNA MODEL 206

The Cessna Model 206 was tested at Cessna Aircraft during the last week in March 2001 and the first week in April. The aircraft was equipped with a three-bladed propeller, 6-cylinder engine with dual exhausts. The engine mount was a bed type mount versus the tubular truss type found on the Model 182 aircraft. The Model 206 could accommodate six passengers; however, it was often used to carry additional cargo with only four passengers, such as the Model 182 aircraft. The Model 206 was equipped with a single door in the forward cabin on the pilot's side of the aircraft and a pair of doors aft behind the co-pilot's door (see Figure 4-1). The aircraft was bare of standard interior; however, damping foam was applied on several panels in the forward section of the aircraft cabin. The damping treatment was a standard application by the airframe manufacturer. The Model 206 aircraft was equipped with nine microphones in the cabin interior and two external microphones, one under the cowling and one downstream from the right hand exhaust pipe. In addition to the 11 microphones, the aircraft was equipped with 13 accelerometers on windows and structural panels, which were identified as potential noise radiators [79].

Figure 4.1 Cessna Model 206 Test Aircraft.

4.1 Cabin Noise and Vibration Spectra

Response data were acquired for the baseline configuration, a firewall treatment configuration where approximately 8 lbs of surface mass treatment was applied to the firewall, and a muffler configuration where "improved mufflers" were installed in addition to the firewall treatment. Spectral data were generated out to 1,000 Hz, which captured the major aircraft responses relative to cabin noise levels. The flight tests were conducted at an engine speed of 2,400 rpm at 75% power cruise at an altitude of 5,000 feet. Detailed spectra and tabular forms of overall noise and vibration levels with responses at major tones were generated [81]. Several observations were noted from the recorded data and only selected data will be given herein to highlight the Model 206 noise and vibration environment.

1. Windshield vibration is dominated by the 120 tone with forward cabin window and panel vibrations exhibiting high vibration levels at the 60 Hz and 120 Hz tones (see Figure 4-2).

2. Firewall treatment appears to greatly reduce center firewall vibration across the spectrum (see Figure 4-3). Vibration reduction in the lower firewall structure was not as apparent, nor was the corresponding reduction in cabin noise levels.

3. The Model 206 cabin microphones exhibited coincident firing and propeller tones as shown in Figure 4-4. However, the cabin microphones off of the aircraft centerline also exhibited responses at 60, 180, and 300 Hz, which are ½ orders of the firing and propeller tones at 120, 240, 360 Hz, etc. These tones are believed to be from the dual exhausts [82]. Consider one side of the dual exhaust seeing two firings and one intake on the first revolution and one firing and two intakes on the second revolution, resulting in three firings per two revolutions on either side of the engine. Thus, a 3/2 order of the engine speed (40 Hz) would generate 60 Hz and higher order harmonics. The phase at microphones AC4 (behind pilot's head) and AC5 (behind co-pilot's head) was evaluated to determine if any conclusions could be drawn about the origin of the tones at 180 Hz and 300 Hz. The magnitude and phase data were extracted from time correlated 0.8-second data traces of the two microphones to look at the phase difference between the microphone responses and are given in Table 4-1. Out-of-phase responses would support the speculation of out-of-phase sources, such as the exhaust ports on either side of the fuselage. It appears that the fundamental propeller and engine exhaust firing tone at 120 Hz is in phase across the cabin, while the second tone at 240 Hz is out-of-phase. The target 180 Hz and 300 Hz tones are both out-of-phase across the cabin. Note that all instrumentation was powered via d.c. batteries and, thus, 60 Hz electrical noise was not present.

4. The high frequency tone just above 900 Hz is clearly present, as was the case for the Model 182 aircraft.

5. Replacing the muffler with the "improved mufflers" made no difference in cabin noise levels. This was verified by the downstream exhaust levels, which remained at a constant level before and after the change in the muffler. The improved mufflers were supplied by Cessna Aircraft for cabin noise evaluation [79].

6. Vibration transmission from the engine through the engine mounts and into supporting bed mount structure was very high. Structure-borne vibration transmission via engine mount tunnel appears highly likely, however, time did not allow further evaluation of this potential noise source.

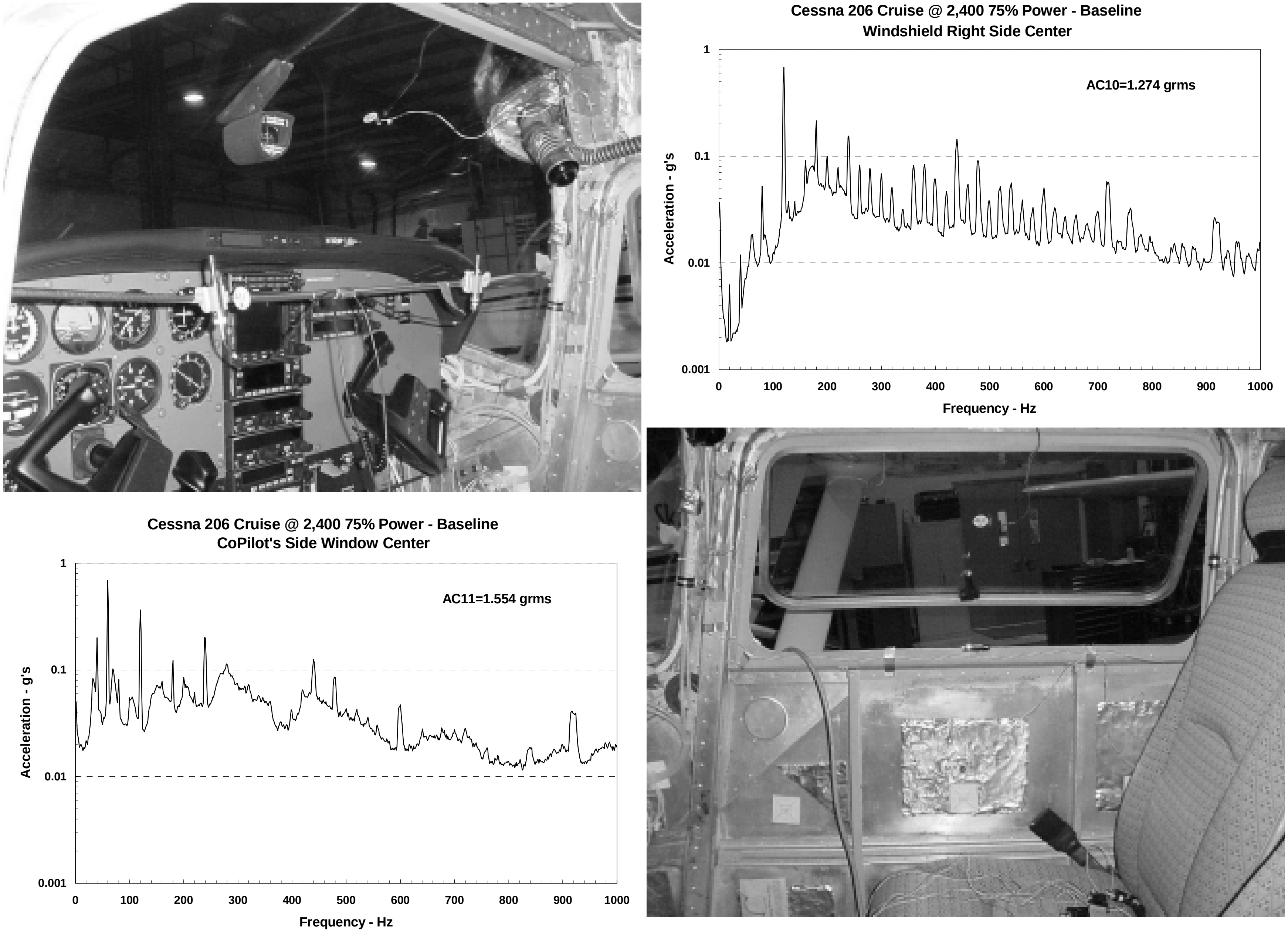


Figure 4.2 Model 206 Window Vibration Spectra.

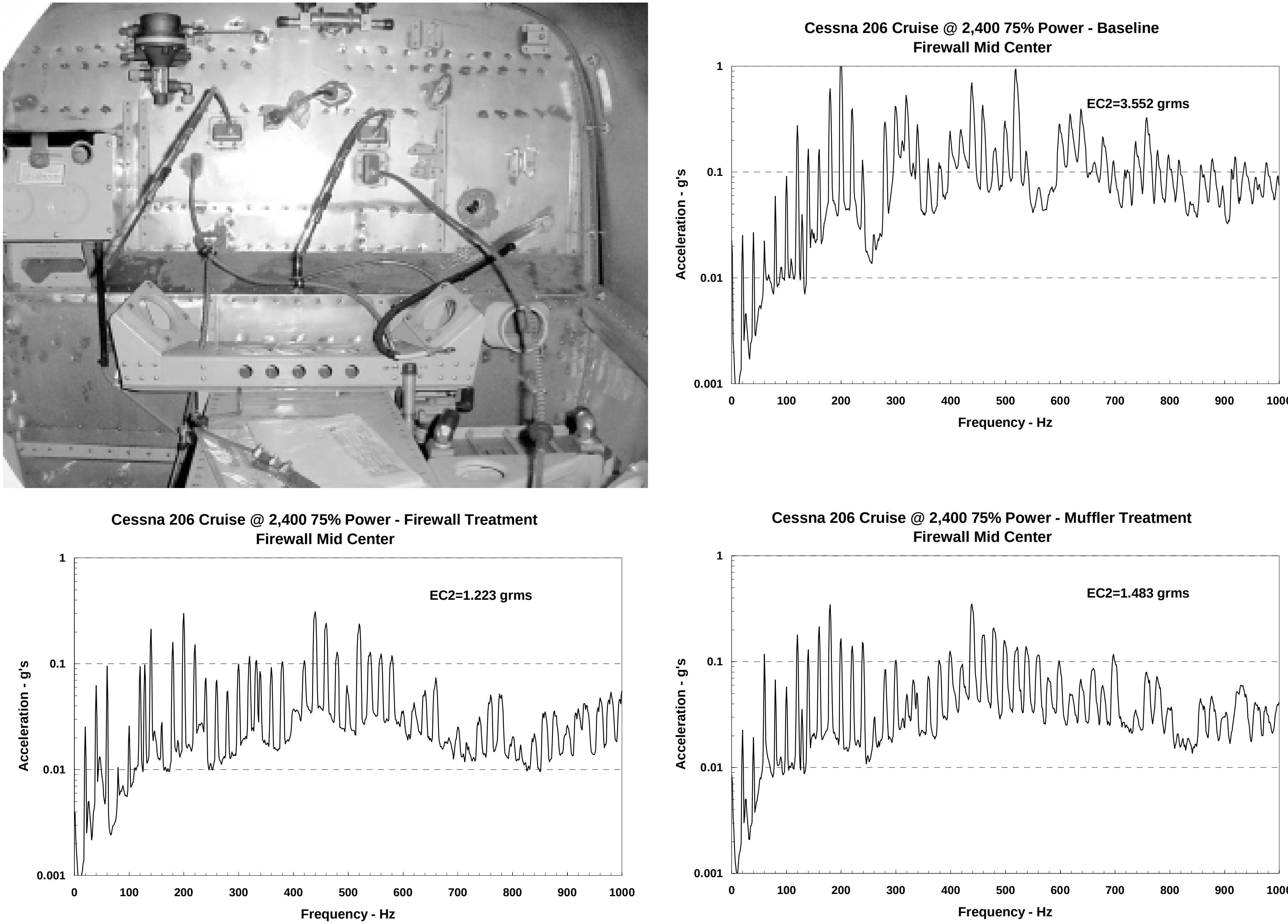


Figure 4.3 Model 206 Firewall Vibration Spectra.

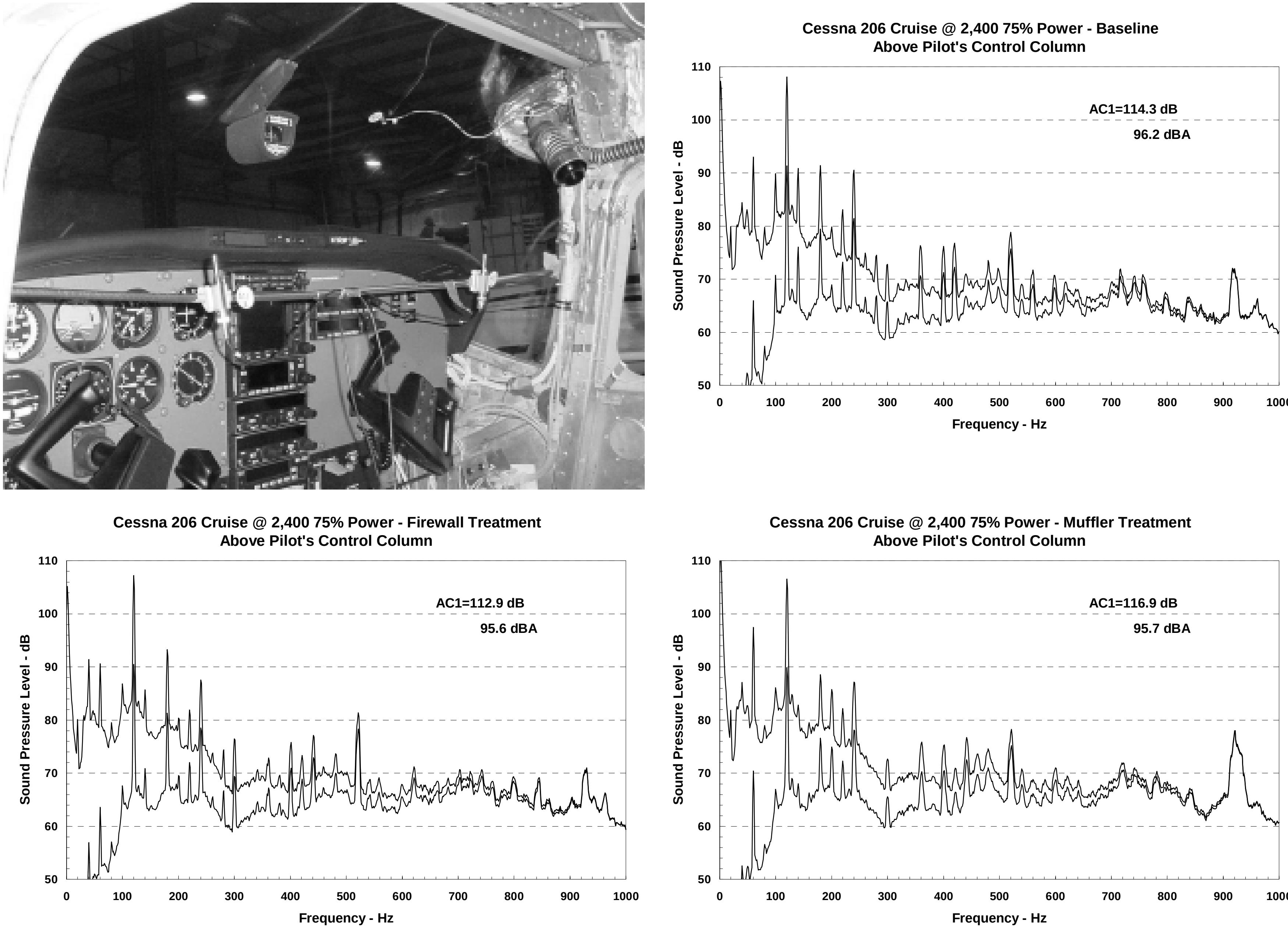


Figure 4.4 Model 206 Cabin Noise Spectra In Forward Cabin.

Table 4.1 Model 206 Tone Phase Evaluation.

Tone Frequency Hz	Microphone AC4		Microphone AC5		AC4-AC5
	Mag - dB	Phase - deg	Mag - dB	Phase - deg	Phase - deg
118.75	80.2	-73	80.2	-68	5
120.00	**106.2**	**-93**	**106.9**	**-91**	**2**
121.25	91.4	89	90.1	73	16
178.75	83.6	-35	79.1	-175	140
180.00	**95.5**	**-57**	**95.4**	**143**	**200**
181.25	85.7	112	85.5	-33	145
238.75	84.4	-160	85.3	48	208
240.00	**91.9**	**-168**	**97.6**	**63**	**231**
241.25	80.2	18	87.9	-143	161
298.75	77.8	148	66.9	-17	165
300.00	**87.5**	**38**	**85.1**	**-137**	**175**
301.25	77.4	-168	80.3	59	227

4.2 Panel Tap Test

An extensive panel tap test was conducted on the Model 206 aircraft to support the development of an Active Structural Acoustic Control (ASAC) investigation by NASA and VPI engineers. Frequency response functions were generated from hammer impact data recorded from seven accelerometers placed on various structural panels and cabin windows. A total of 22 data sets were generated during the study. In general, the panels were very rich in low frequency response [80].

4.3 Linear Array Measurements

The purpose of this effort was to evaluate the acoustic environment of the aircraft interior and characterize the environment as either standing wave or free field traveling wave at select frequencies of interest. The acoustic array consisted of 16 microphones spaced 6 inches apart. The array was positioned near the centerline of the aircraft at mid-window height. Microphone A1 was located just aft of the instrument glare shield. A photograph of the installed array is shown in Figure 4-5 and a typical noise spectrum, recorded at the first microphone in the array is shown in Figure 4-6. In general a slight decrease in SPL occurs from forward to aft along the fuselage with the total decrease being approximately 2.5 dBA over the 90-inch span of the array [78].

With the engine speed set at 2,400 rpm, the firing and the three-bladed propeller fundamental frequencies are at 120 Hz. The relative magnitude and phase variations along the aircraft for the 120 Hz tone and first harmonic at 240 Hz are given in Figures 4-7 and 4-8, respectively. The equivalent linear phase distribution for a traveling wave is given in the figures. The 240 Hz harmonic exhibits a strong traveling wave phase distribution along the entire length of the cabin.

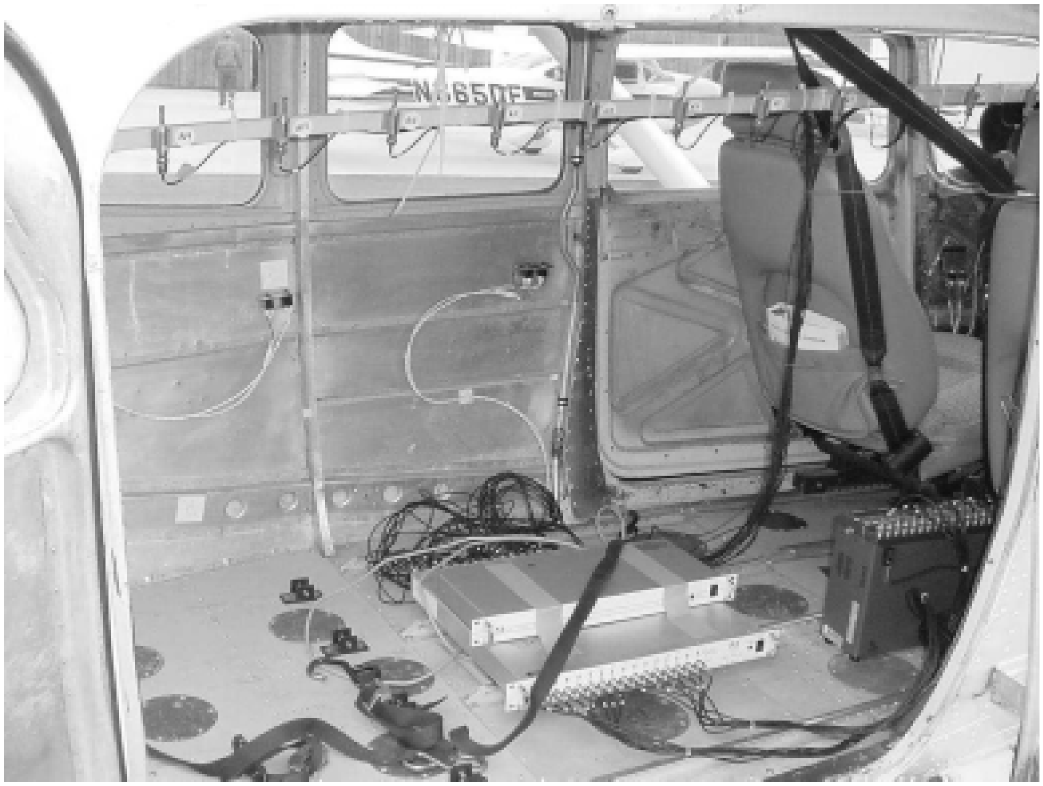


Figure 4.5 Cessna 206 Microphone Array.

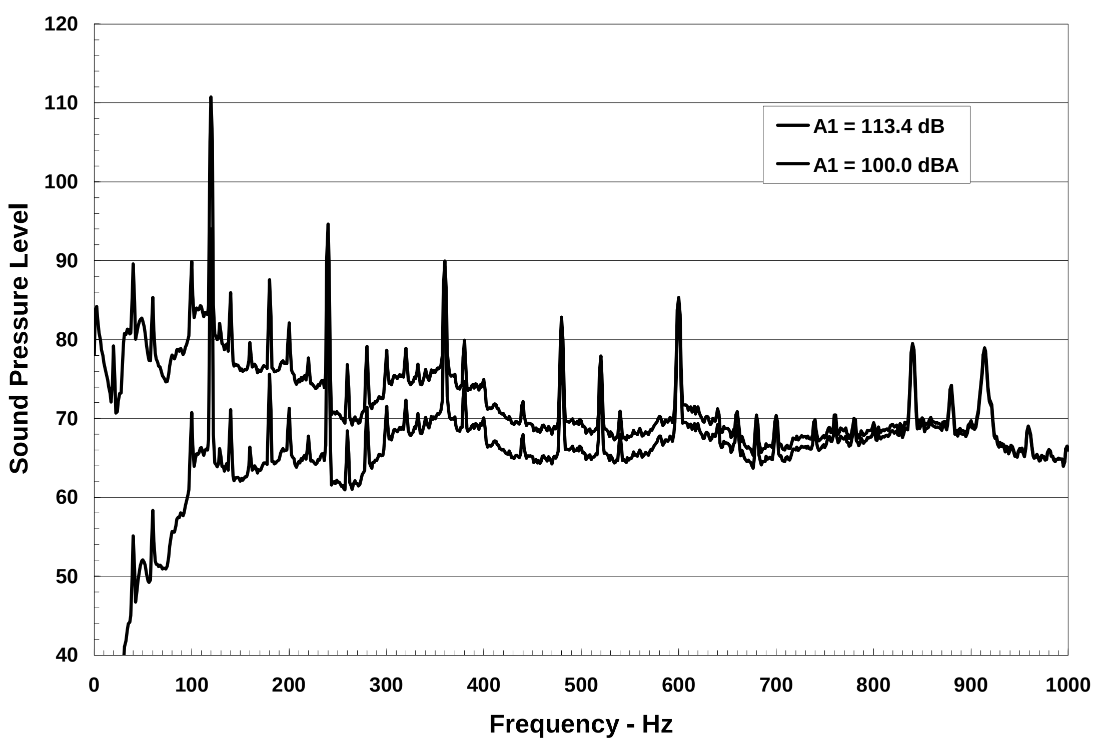


Figure 4.6 Narrow Band Spectrum at Microphone A1.

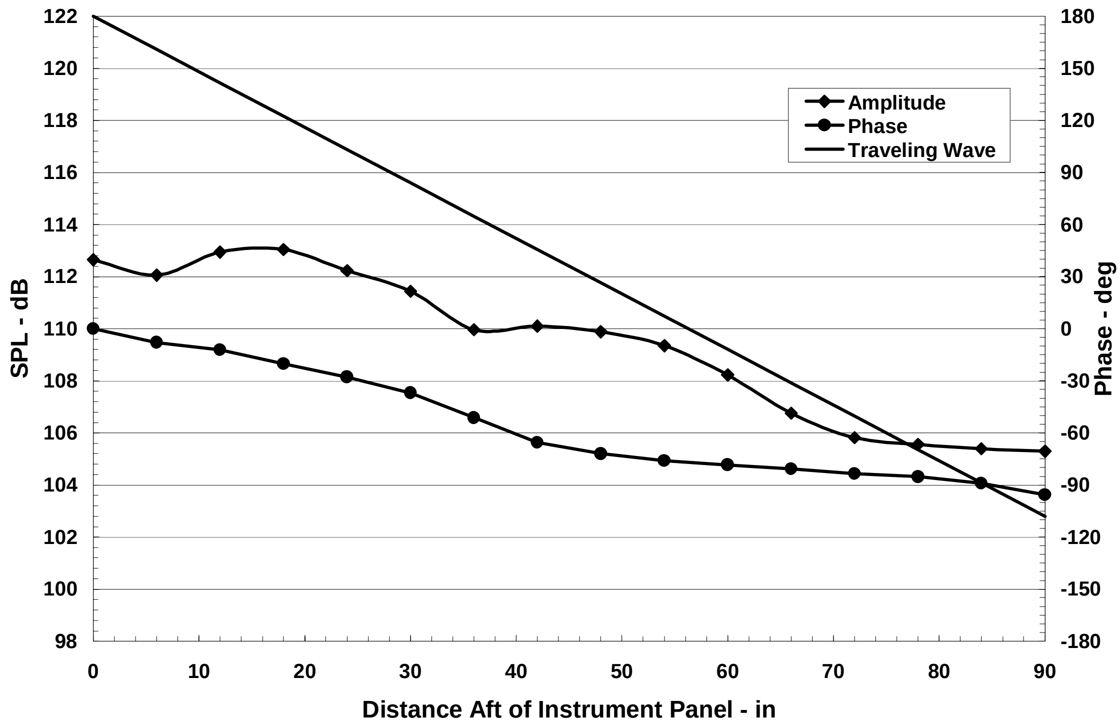


Figure 4.7 Model 206 Microphone Array Measurement – 120 Hz Tone.

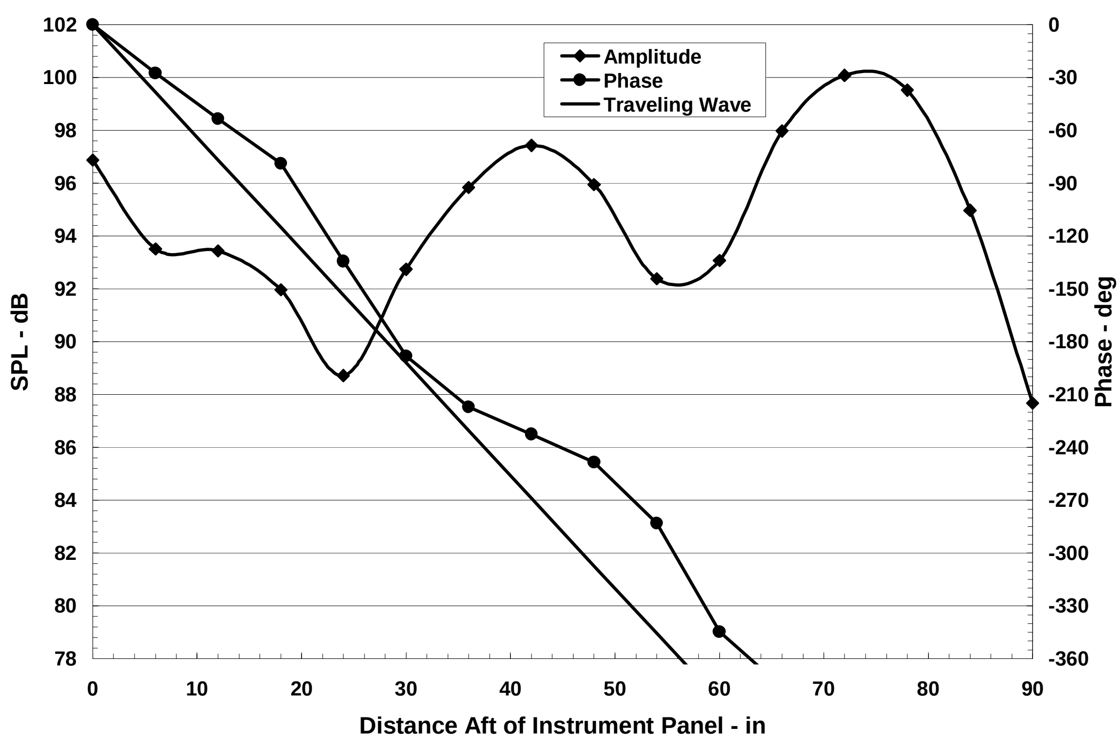


Figure 4.8 Model 206 Microphone Array Measurement – 240 Hz Tone.

5. CESSNA MODEL 182F

Flight tests were conducted on a Cessna Model 182F during the two-week period from August 10 through August 23, 2001 with the purpose to evaluate passive and active noise control measures for cabin noise reduction. A photograph of the test aircraft is given as Figure 5-1. The aircraft was fitted with a three-bladed propeller supplied to the project by McCauley Propeller Systems. Flight test operations were carried out of Check Six Aviation, San Antonio, Texas. All recorded flight tests of the aircraft were conducted at 2,400 rpm, 75% power cruise at an altitude of 5,000 feet. The instrumentation schedule used during the flight tests included both microphones and accelerometers, according to the schedule given in Table 5-1. In the active control evaluation, several of the accelerometers were replaced by four microphones (AC31-AC34) to aid in global control as noted in the table. Detailed spectra for all measured response parameters for the various control configurations are contained in the References 89 through 95.

Figure 5.1 Cessna Model 182F Test Aircraft.

The cabin noise control challenge for the test aircraft is best visualized by the summary of bare cabin microphone spectra given in Figure 5-2. Here we see the propeller and engine firing harmonics at 120 Hz, 240 Hz, 360 Hz, 480 Hz, 600 Hz, 720 Hz clearly dominate the spectra, along with a cluster of tones from 460 Hz through 520 Hz at a 20 Hz frequency increment. The immediate noise control targets are the coincident fundamental propeller and exhaust firing tones at 120 Hz, the first harmonic at 240 Hz, and the cluster of tones around 500 Hz.

Table 5.1 Instrumentation Schedule During Passive Treatment Evaluation.

Channel	Type – Nomenclature	Description
1	Optical Pickup	Prop Fundamental 3 per rev.
2	Accelerometer – EC12	Firewall normal acceleration – mid center
3	Microphone – EC14	Firewall sound pressure level – upper center
4	Microphone – AC1	Above pilot's control column
5	Microphone – AC2	Above copilot's control column
6	Microphone – AC3	Near right rear seat passenger's head
7	Microphone – AC4	Near left rear seat passenger's head
8	Microphone – AC20	Between Pilot and Co-pilot ear height
9	Microphone – AC21	Behind pilot's head
10	Microphone – AC22	Behind co-pilot's head
11	Accelerometer –SP1	Structural Panel Pilot Side Foot Well
11a	Microphone – AC31	Forward Cabin Pilot Side
12	Accelerometer – SP3	Structural Panel Pilot Side Mid Cabin
12a	Microphone – AC32	Forward Cabin Co-Pilot Side
13	Accelerometer – AC7	Windshield right side
13a	Microphone – AC33	Far Aft Cabin Pilots Side
14	Accelerometer – AC9	Pilot's side window center
14a	Microphone – AC34	Far Aft Cabin Co-Pilot Side
15	Accelerometer – AC11	Right rear passenger's window center
16	Accelerometer – SP2	Structural Panel Forward Center Roof Panel

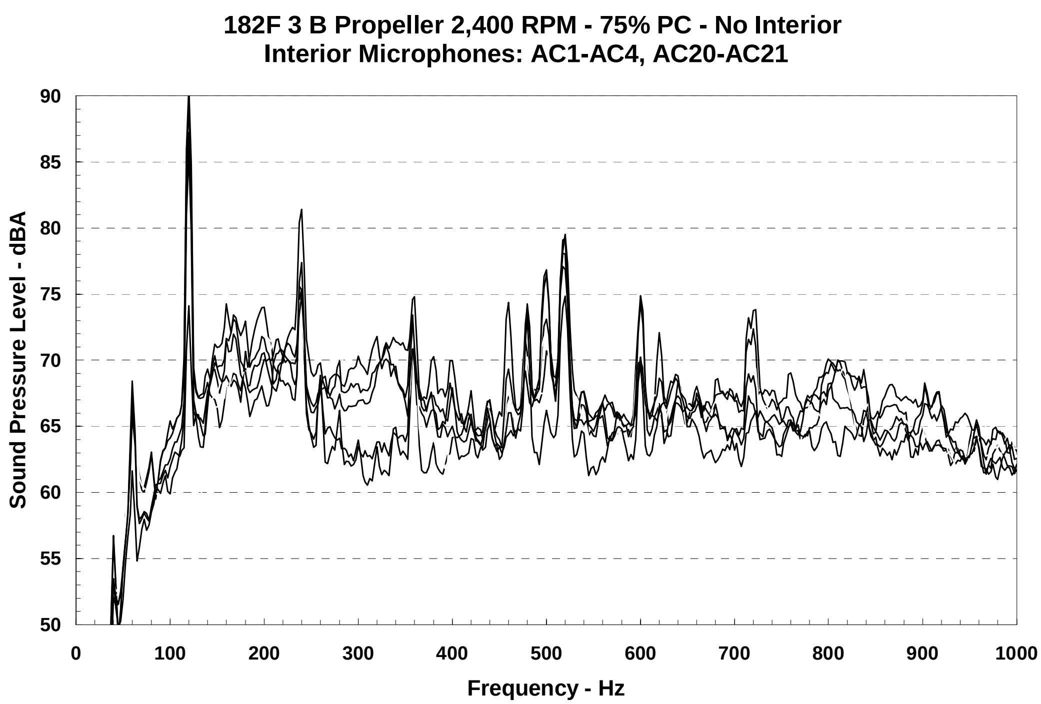


Figure 5.2 Model 182F Bare Cabin Interior Noise Spectra.

5.1 Passive Treatment Evaluation

Table 5-2 lists the passive treatment evaluations and the nomenclature used to reference a particular treatment. A summary of the weights of the aircraft interior and passive treatments is given in Table 5-3 [89].

Table 5.2 Passive Treatment Test Configurations.

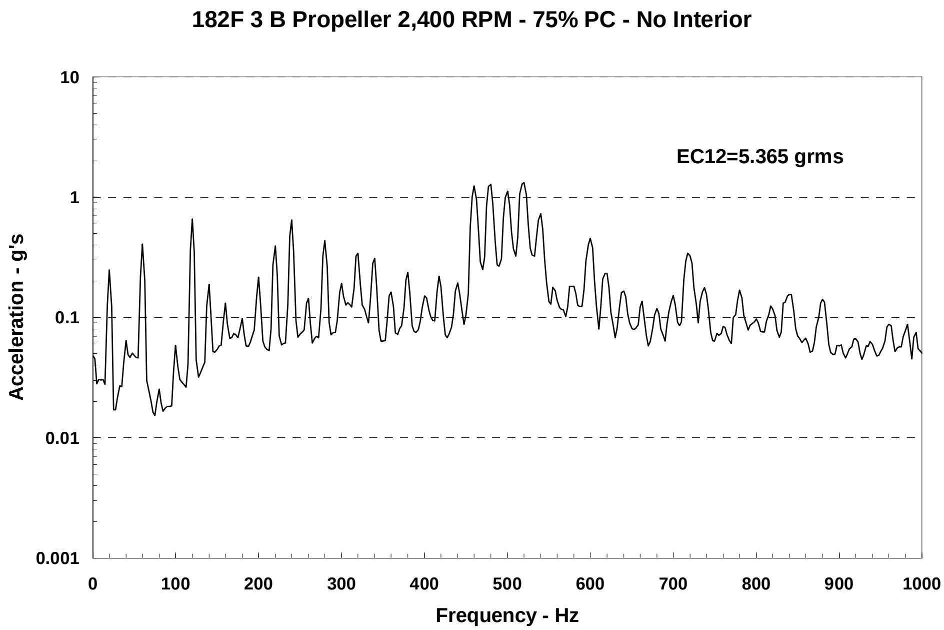
Test Configuration	Nomenclature	Est. Weight - lbs
Standard Interior Trim	Std. Interior	43.08
Bare Fuselage – No Trim or Rear Seats	No. Interior	0.0
Firewall Treated with WB10 ~ 90% Coverage	Firewall Only	9.62
Distributed Vibration Absorbers – Standard 120 Hz and 240 Hz with Firewall Treatment – Run #1	DVAs1 + FW	16.85
Distributed Vibration Absorbers – Standard 120 Hz and 240 Hz with Firewall Treatment with WB10 on all Side Windows	DVAs1 + FW + SW	27.23
Distributed Vibration Absorbers – Standard 120 Hz and 240 Hz with Firewall Treatment – Run #2	DVAs2 + FW	16.85
Equivalent Masses Replacing Standard DVAs with Firewall Treatment	DVA Masses	16.85
Distributed Vibration Absorbers – Special Design Aimed at 240 Hz Broadband with Firewall Treatment	DVAs Spec + FW	14.70

Table 5.3 Passive Treatment Weights.

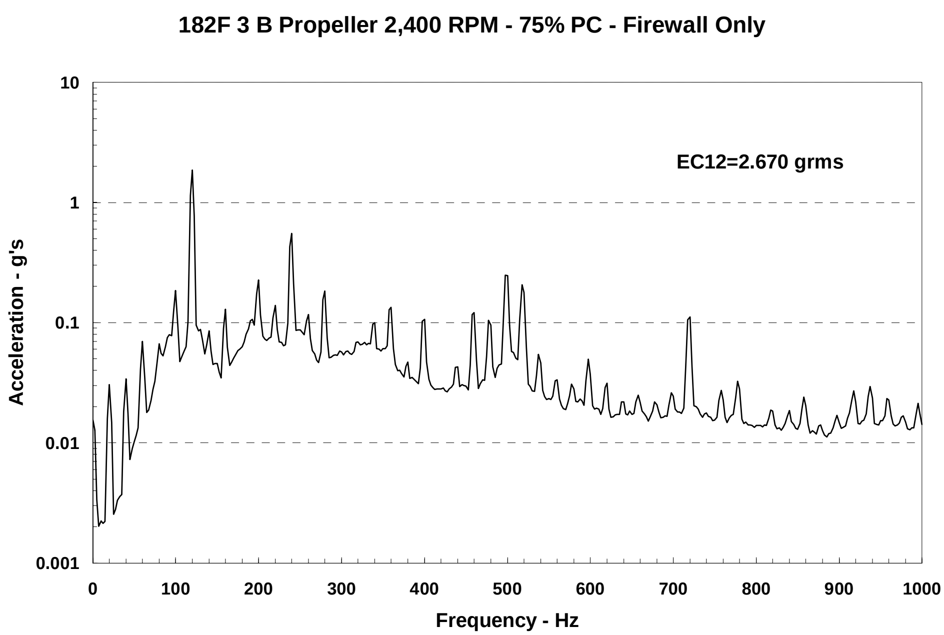
Treatment	Weight (lbs)	Comments
Standard Interior	43.08	Not including rear seat at 30.52 lbs
Firewall Treatment WB10	9.62	Approximately 90% coverage @ 1.0 lbs/sq.ft.
Side Window Treatments WB10	10.38	100% coverage @ 1.0 lbs/sq.ft.
Standard DVAs	7.23	22 ea. 120 Hz @ 5.68 lbs and 20 ea. 240 Hz @ 1.55 lbs
Special DVAs	5.08	20 ea. 240 Hz Broadband @ 5.08 lbs

5.1.1 Firewall Treatment

The WB10 treatment, a 1.0 lbs/sq. ft. self-adhesive backed loaded vinyl, was used as mass loading over approximately 90 percent of the firewall area. The mass loading treatment reduced the firewall vibration levels in most all the spectra, except at the propeller and engine firing fundamental at 120 Hz, as is shown in Figure 5-3. It appears that a firewall resonance may have been shifted down to near the 120 Hz tone, thereby, producing an amplified vibration response. The source of the 460 Hz to 520 Hz cluster of energy is not as apparent as the propeller and engine firing harmonics; however, it was believed to be associated with engine valve noise from the CRA results presented in Section 2. This is supported by the firewall vibration reduction given in Figure 5-3 and the corresponding under cowling noise spectra given in Figure 5-4, both having rich response in the mid frequency region. Unfortunately, the cabin noise reduction in the 460 Hz to 520 Hz range does not directly track the firewall vibration reduction at the particular point of measurement and, therefore, the source must be more widely distributed.



a) No Treatment.



b) Firewall Treatment Applied.

Figure 5.3 Effect of Firewall Treatment on Firewall Vibration.

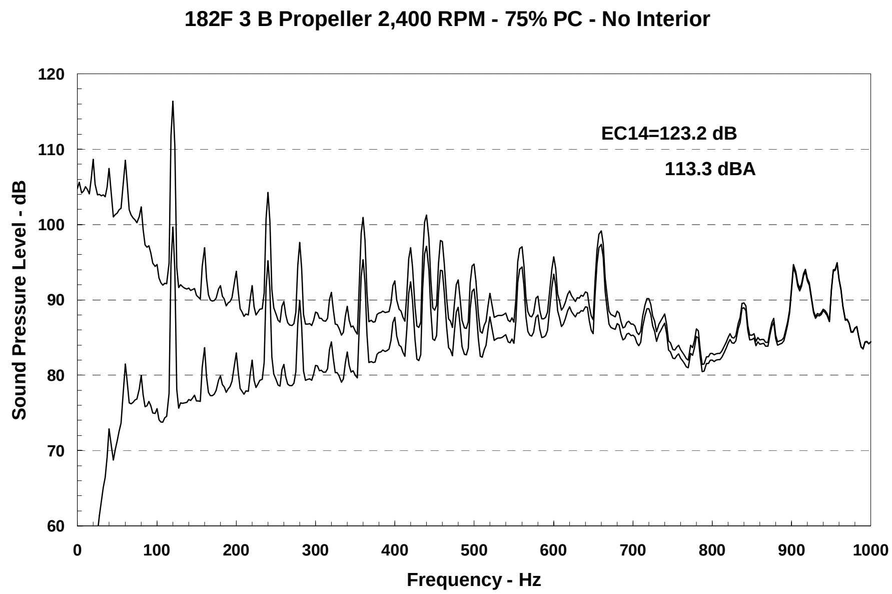


Figure 5.4 Typical Under Cowling Noise Spectra.

5.1.2 Distributed Vibration Absorbers

The Distributed Vibration Absorbers (DVAs) were developed by VPI engineers and consist of a distributed mass plate supported on a distributed stiffness and damping foam material. The DVAs are designed to have a resonant tuned response at prescribed frequencies corresponding to the driven excitation of the structural panel to which they are attached. Thus, tuning the DVAs to the 120 Hz and 240 Hz tones and applying them to the various cabin panels should produce reduced panel vibration and, thus, reduce noise radiation into the cabin. A photograph of the DVAs used during the evaluation is given in Figure 5-5 and photographs of typical installations are given in Figures 5-6 and 5-7. The standard installation consisted of 22 of the larger 120 Hz DVAs and 20 of the smaller 240 Hz DVAs. The DVAs were placed on nearly all exposed structural panels of the aircraft. The larger panels, such as sidewall panels, were fitted with both 120 and 240 Hz DVAs. Two flight tests were conducted with the standard DVA set to provide a check on repeatability. Limp masses, cut from WB10, of equivalent weights to the standard DVAs replaced the DVAs to provide a check on the blocking mass effects of the DVAs versus their absorptive characteristics. A special set of DVAs aimed at the 240 Hz tone (see Figure 5-5) was also flight-tested.

Sound pressure levels at the target 120 Hz and 240 Hz tones for the seven cabin microphones were extracted from the various in-flight spectra and listed in Tables 5-4 and 5-5, respectively. The under cowling microphone, EC14, levels are also given to indicate the steadiness of the source. Several observations can be drawn from the data presented in Tables 5-4 and 5-5, and reference is made to the detailed evaluations contained in Reference 91.

1. The firewall treatment provided a measurable level of noise source isolation in the forward cabin for the 120 Hz tone and in the aft cabin for the 240 Hz tone.

Figure 5.5 Distributed Vibration Absorbers.

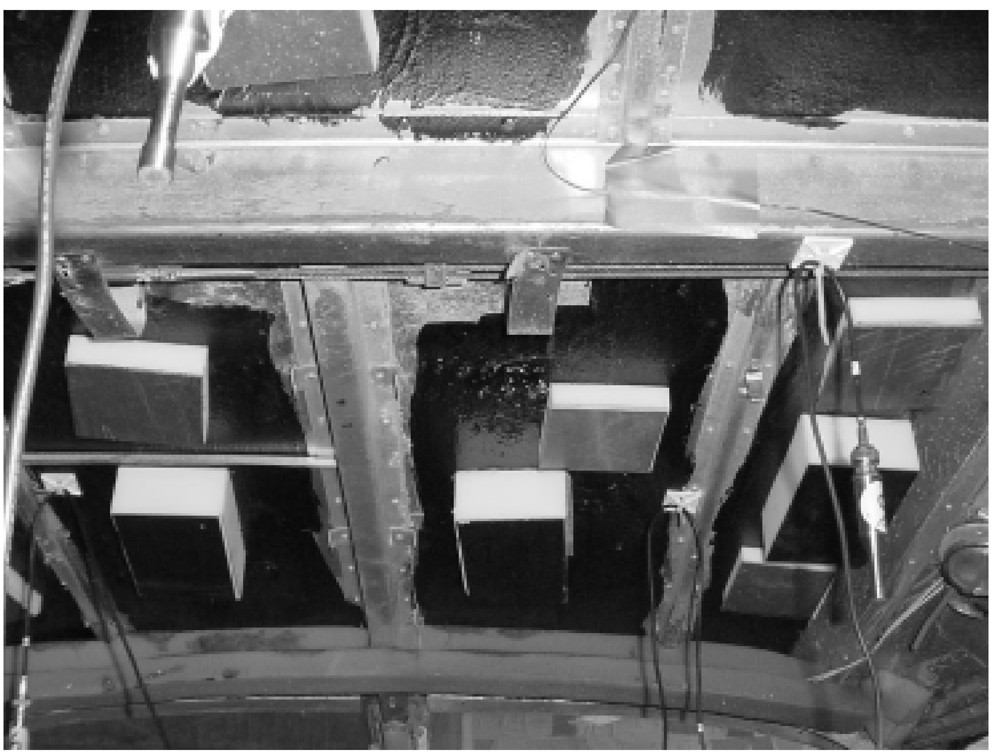


Figure 5.6 Typical DVA Installation: Cabin Roof.

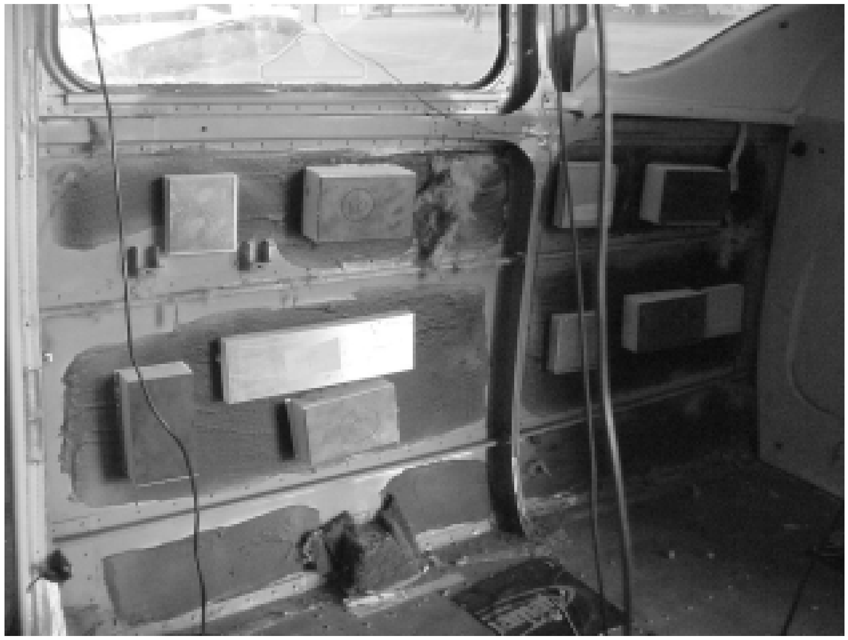


Figure 5.7 Typical DVA Installation: Cabin Sidewall.

Table 5.4 Effect of Treatment Configuration on the 120 Hz Tone.

	Microphone – dBA							
Configuration	**EC14**	**AC1**	**AC2**	**AC3**	**AC4**	**AC20**	**AC21**	**AC22**
No Interior	101.7	92.7	91.4	78.8	81.4	89.3	87.7	76.6
Std. Interior	102.1	87.8	87.7	75.6	84.2	84.5	86.5	68.5
DVAs1 + FW	101.7	88.6	85.9	79.1	79.7	80.9	83.8	74.8
DVAs1 + FW + SW	102.1	88.7	86.7	78.1	78.3	82.2	83.0	69.4
DVA Masses	101.9	88.5	87.6	77.2	79.7	82.4	83.6	74.5
DVAs2 + FW	102.8	87.7	85.2	70.6	80.5	86.1	85.9	74.9
DVAs Spec + FW	102.1	84.4	81.6	83.9	83.6	84.3	87.5	85.7
Firewall Only	102.0	90.0	87.4	71.7	76.0	89.7	87.9	77.6
Minimum	101.7	84.4	81.6	70.6	76.0	80.9	83.0	68.5
Maximum	102.8	92.7	91.4	83.9	84.2	89.7	87.9	85.7

Table 5.5 Effect of Treatment Configuration on the 240 Hz Tone.

	Microphone – dBA							
Configuration	**EC14**	**AC1**	**AC2**	**AC3**	**AC4**	**AC20**	**AC21**	**AC22**
No Interior	97.9	79.2	78.8	78.4	80.9	80.5	84.8	78.4
Std. Interior	99.0	75.3	75.8	72.2	72.7	77.0	79.7	75.4
DVAs1 + FW	99.0	76.5	80.9	76.5	81.5	82.3	83.8	74.5
DVAs1 + FW + SW	99.3	74.3	80.3	79.6	84.4	82.4	86.0	76.4
DVA Masses	99.9	75.9	80.4	76.3	76.6	83.5	78.9	79.0
DVAs2 + FW	99.3	81.6	79.8	77.2	81.4	80.1	83.1	79.0
DVAs Spec + FW	100.2	79.3	82.7	80.4	74.4	80.1	79.4	81.5
Firewall Only	99.6	79.0	77.5	76.5	76.7	78.1	79.1	77.2
Minimum	97.9	74.3	75.8	72.2	72.7	77.0	78.9	74.5
Maximum	100.2	81.6	82.7	80.4	84.4	83.5	86.0	81.5

2. The standard cabin interior performed as well as any of the treatments at the 240 Hz tone.

3. The DVAs masses performed nearly as well as the standard DVAs for either of the tones analyzed.

4. The special DVAs, aimed at the 240 Hz tone, performed better in the forward cabin at 120 Hz than any of the other control measures and less effective in the forward cabin at 240 Hz than the standard DVAs.

5.2 Active Structural Acoustic Control

An Active Structural Acoustic Control (ASAC) system, developed by VPI and NASA engineers, was flown on the Model 182F aircraft aimed at control of the 120 Hz and 240 Hz tones. The ASAC system consisted of placing small Motran inertial exciters on low impedance, high mobility, locations within the aircraft along with collocated accelerometers. Six to eight actuators were used in the control scheme; photographs of typical actuator installations are given in Figures 5-8 and 5-9. Various combinations of actuators and error microphones were investigated to obtain an optimum control set [92, 93]. The error microphones were those listed under channels 4 through 11 in Table 5-1, which covered both the forward and aft cabin areas. During flight, the control algorithm was turned on and then off to record sample averaged responses at each of 12 sensors. The best performing ASAC system consisted of 8 actuators and 8 error microphones, and the control achieved for selected tones in the spectrum are given in Table 5-6. The difference in tone levels when the ASAC system was activated is listed in the last set of data in Table 5-6. The maximum control level achieved at 120 Hz was 12.3 dB at AC4, and the minimum was a slight increase at the far aft cabin at AC33. AC33 was not included in the error microphone set. The minimum control at the error microphones was 2.2 dB at AC22. The maximum control achieved at 240 Hz among the error microphones was also at AC4 at a level of 4.8 dB, and the minimum control was actually a gain of 5.5 dB on the opposite side of the aircraft at AC3. The far aft cabin microphone AC34, not included in the error microphone set, exhibited a rather large

Figure 5.8 Typical Motran Installation: Co-Pilot's Door.

increase in noise level. Thus, the ASAC system did not achieve global control in the aircraft cabin.

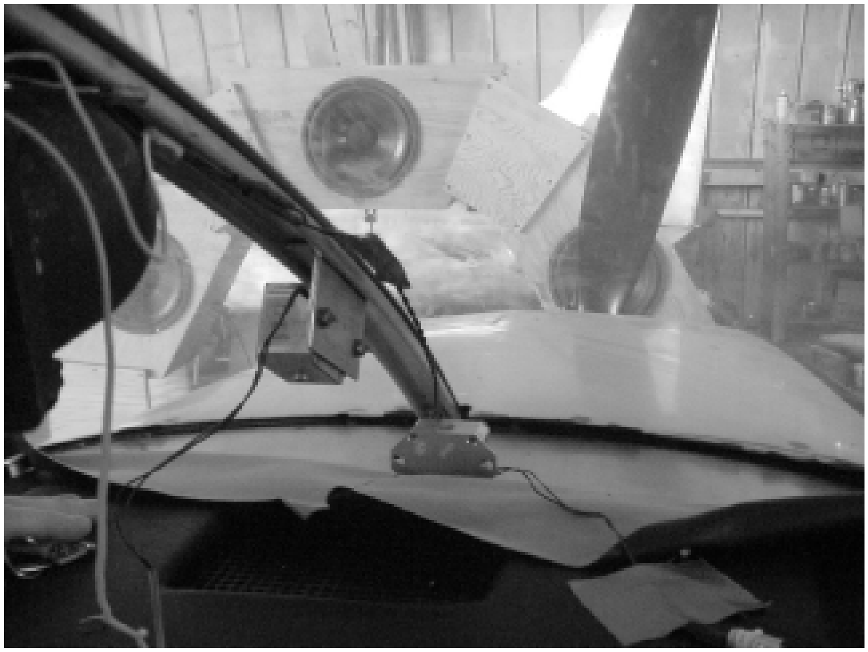


Figure 5.9 Typical Motran Installation: Windshield.

The ASAC system was flown with the standard set of DVAs and the firewall treatment. By comparing noise levels to the baseline runs with no interior and firewall, only the combined effects of passive and active controls can be sorted out as given in Table 5-7. The level of control for the combined ASAC, standard DVAs, and firewall treatment at the 120 Hz tone was quite high for all but one of the error microphones, microphones AC31 through AC34 were not included during the baseline flights. Summary spectra out to 500 Hz for the aircraft with no interior, standard interior, and full treatment consisting of the best ASAC system with DVAs and firewall treatment are given in Figures 5-10 through 5-13, respectively, for microphones AC1 through AC4. Here we see a good level of control for the 120 Hz tone with little control of the 240 Hz tone with degraded performance in the higher frequencies over that of the standard interior [94, 95].

Overall noise control performance in the frequency range out to 1,000 Hz is summarized in Table 5-8. In general, the standard aircraft interior provided nearly 4 dB noise reduction while the full treatment, consisting of ASAC plus standard DVAs and firewall treatment, provided only 3 dB overall noise reduction. It appears that a combination of passive and active treatment for low frequency control and standard interior for high frequency control may provide the optimum control measure for the aircraft.

Table 5.6 Best ASAC Results: 8 Actuators and 8 Error Microphones.

ASAC On												
Frequency	**EC14**	**AC1**	**AC2**	**AC3**	**AC4**	**AC20**	**AC21**	**AC22**	**AC31**	**AC32**	**AC33**	**AC34**
(Hz)	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**
120	100.7	80.5	76.6	71.0	69.4	75.0	72.7	77.4	78.3	81.4	78.2	77.1
240	97.6	74.0	76.7	79.9	77.4	72.5	75.2	73.4	71.9	75.6	81.3	83.9
360	96.2	75.7	71.8	71.3	72.9	80.0	76.1	75.5	75.7	79.9	74.0	75.6
480	87.6	78.9	80.6	75.6	72.6	77.4	73.9	80.2	74.7	79.1	72.7	78.5
520	95.9	83.4	80.7	76.5	77.5	76.6	77.0	75.0	82.3	83.0	72.6	67.8
560	99.0	74.5	69.8	68.9	70.7	68.2	69.0	68.3	70.5	72.7	67.7	68.6
600	93.9	76.7	79.0	72.0	72.5	72.6	74.0	73.6	76.3	79.3	71.8	72.8
Overall	113.4	93.8	93.2	90.9	91.5	91.2	92.0	91.8	94.8	94.3	92.5	92.2
ASAC Off												
Frequency	**EC14**	**AC1**	**AC2**	**AC3**	**AC4**	**AC20**	**AC21**	**AC22**	**AC31**	**AC32**	**AC33**	**AC34**
(Hz)	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**
120	98.9	86.9	86.3	78.6	81.7	80.2	83.0	79.6	87.9	87.7	77.0	77.9
240	95.7	75.3	76.9	74.4	82.2	75.9	77.8	76.2	74.9	79.9	83.6	73.4
360	95.7	72.8	73.0	70.7	71.0	74.8	73.4	72.9	74.4	78.1	72.5	69.7
480	94.1	74.3	77.5	73.0	70.1	75.8	71.9	75.6	73.3	76.0	68.2	73.4
520	100.7	79.1	74.7	71.7	73.7	71.2	72.4	70.2	74.7	78.5	69.0	67.7
560	93.1	70.1	69.0	66.2	67.6	68.5	68.5	68.8	70.4	70.9	68.8	67.2
600	89.6	70.7	72.0	70.1	67.1	70.2	71.4	71.0	73.3	73.0	68.7	66.5
Overall	113.3	94.2	94.7	91.4	92.2	91.8	92.5	92.4	95.2	95.1	91.7	91.6
Effect of ASAC												
Frequency	**EC14**	**AC1**	**AC2**	**AC3**	**AC4**	**AC20**	**AC21**	**AC22**	**AC31**	**AC32**	**AC33**	**AC34**
(Hz)	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**	**SPL dBA**
120	1.8	-6.4	-9.7	-7.5	-12.3	-5.2	-10.4	-2.2	-9.6	-6.4	1.2	-0.8
240	1.9	-1.3	-0.2	5.5	-4.8	-3.4	-2.7	-2.8	-3.0	-4.4	-2.2	10.5
360	0.5	2.9	-1.3	0.6	1.9	5.2	2.7	2.7	1.3	1.8	1.4	5.9
480	-6.5	4.6	3.1	2.6	2.5	1.6	2.0	4.7	1.5	3.1	4.6	5.2
520	-4.8	4.3	6.0	4.7	3.8	5.3	4.6	4.8	7.6	4.5	3.6	0.1
560	5.9	4.4	0.8	2.7	3.2	-0.4	0.6	-0.5	0.0	1.8	-1.1	1.5
600	4.3	6.0	7.0	2.0	5.4	2.4	2.6	2.6	3.0	6.4	3.1	6.3
Overall	0.1	-0.4	-1.5	-0.5	-0.8	-0.6	-0.5	-0.6	-0.4	-0.8	0.8	0.6

Table 5.7 Best ASAC Plus Passive Treatment.

Effect of ASAC + Standard DVAs												
Frequency	EC14	AC1	AC2	AC3	AC4	AC20	AC21	AC22	AC31	AC32	AC33	AC34
(Hz)	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA
120	-1.3	-9.4	-10.8	-0.7	-6.6	-14.7	-15.2	-0.2	-13.6	-8.2	0.0	-8.4
240	-2.0	-4.9	-0.8	3.3	0.7	-5.6	-3.9	-3.9	-4.3	0.0	1.6	2.5
360	-3.1	5.5	-4.9	-4.9	-4.6	8.4	-1.0	1.6	0.5	1.0	0.4	4.1
480	-7.0	2.9	-0.1	-5.6	-3.7	-3.1	3.5	5.0	-3.0	1.7	-2.1	2.2
520	1.6	3.4	-1.1	-6.1	-2.6	-4.9	-3.1	-4.2	5.4	4.4	1.3	-9.6
560	-0.7	1.9	-1.4	-0.4	1.4	-1.5	-1.2	-2.0	-1.8	0.6	-3.4	-3.4
600	-2.4	-3.0	1.9	-6.9	-5.1	-2.1	-5.0	-2.3	0.4	3.9	0.2	0.9
Overall	0.3	-0.8	-0.8	-2.6	-1.4	-3.3	-2.4	-1.5	-0.9	-0.9	-0.1	-2.4

Effect of ASAC + Standard DVAs + Firewall Treatment												
Frequency	EC14	AC1	AC2	AC3	AC4	AC20	AC21	AC22				
(Hz)	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA	SPL dBA				
120	-1.0	-12.2	-14.8	-7.8	-12.1	-14.2	-15.0	0.8				
240	-0.3	-5.1	-2.1	1.5	-3.5	-8.0	-9.6	-5.0				
360	-2.4	0.6	-3.4	-4.0	-3.3	3.8	-2.5	1.0				
480	-5.3	3.9	2.9	-0.8	-1.7	1.0	1.0	2.6				
520	4.4	0.2	-0.4	-0.4	2.9	-2.0	-4.9	-8.0				
560	0.7	4.4	-1.1	0.5	2.5	1.0	-2.2	-3.4				
600	-3.3	-1.8	4.5	-4.4	0.3	-0.7	-0.2	-4.3				
Overall	0.2	-2.3	-2.2	-1.8	-1.6	-3.0	-3.0	-2.2				

Table 5.8 Summary of Overall Noise Control.

Treatment	Overall Sound Pressure Level - dBA							
	AC1	AC2	AC3	AC4	AC20	AC21	AC22	Energy Average
Bare Cabin	96.0	95.4	92.7	93.1	94.2	95.0	93.9	94.5
Standard Interior	93.2	93.1	87.1	88.7	90.5	90.7	87.4	90.7
Full Treatment	92.6	92.2	90.6	90.3	90.9	91.1	91.2	91.3

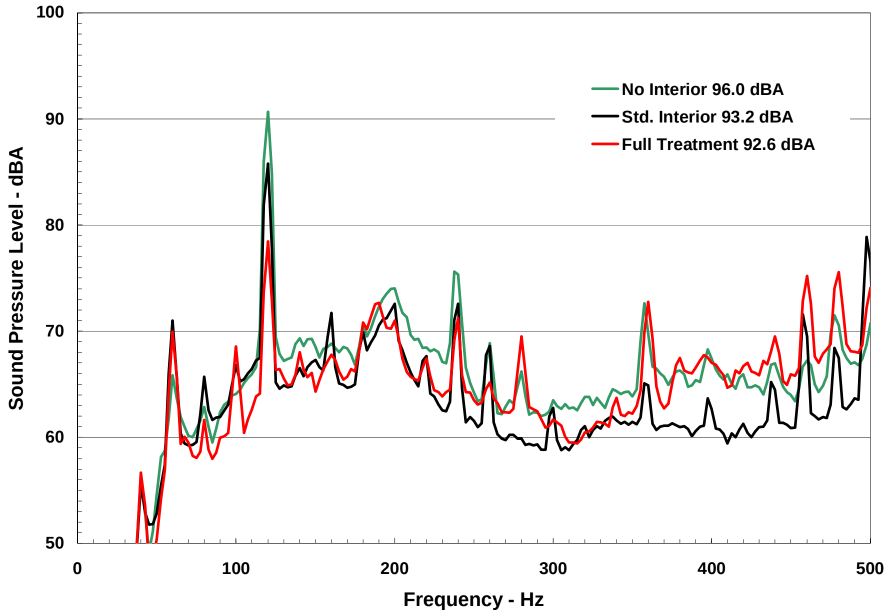


Figure 5.10 Summary of Control at AC1.

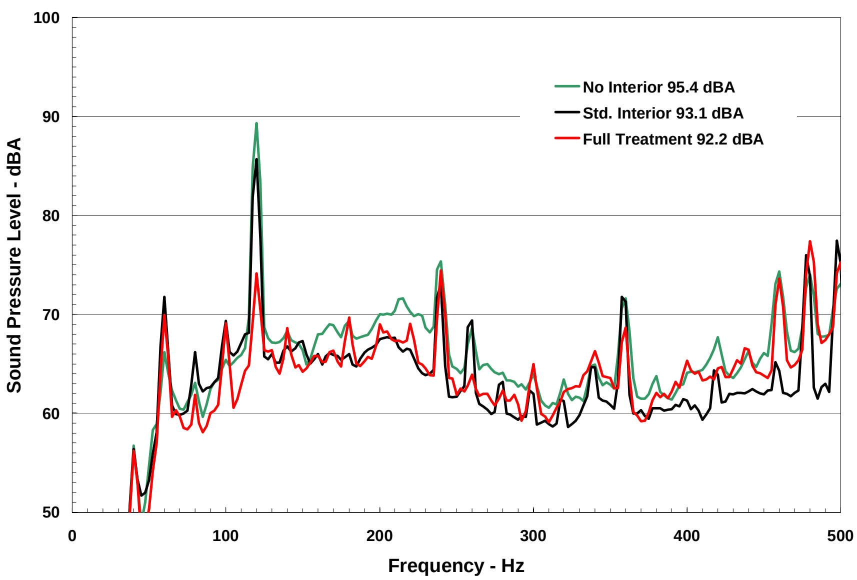


Figure 5.11 Summary of Control at AC2.

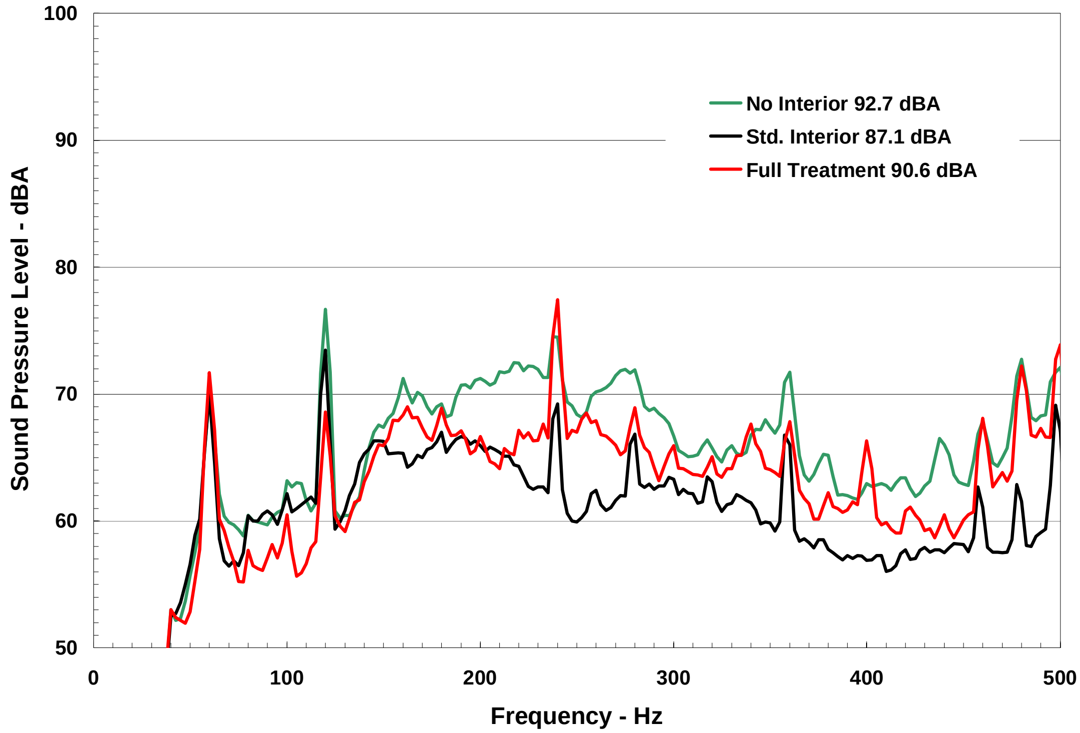


Figure 5.12 Summary of Control at AC3.

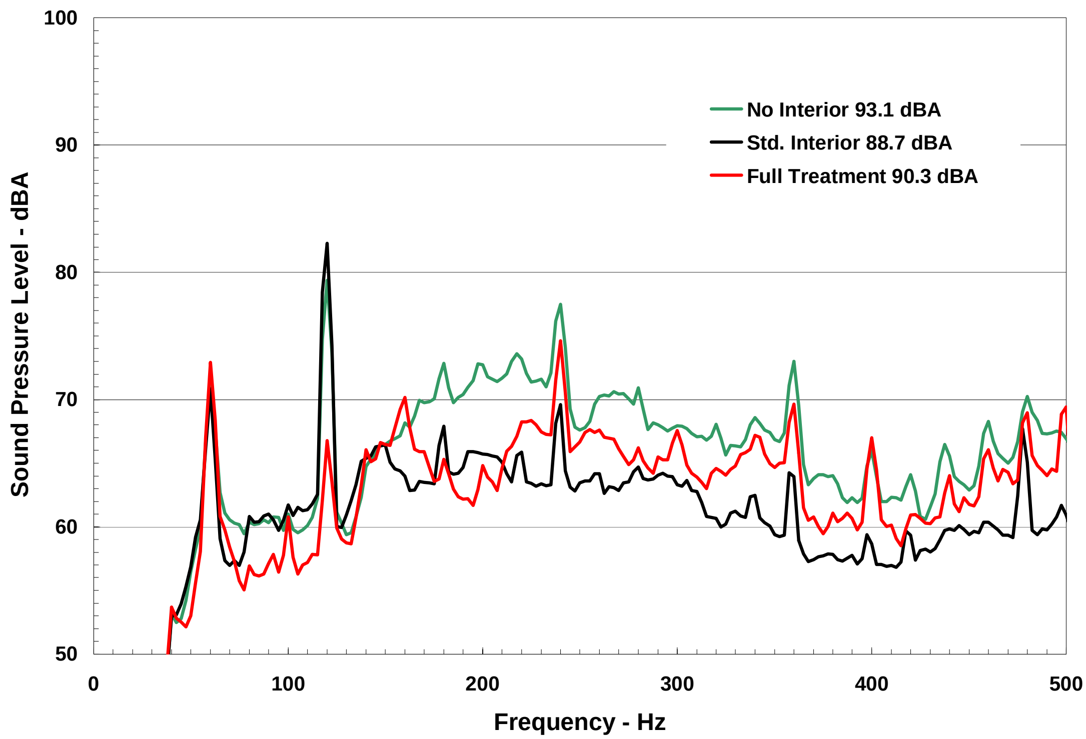


Figure 5.13 Summary of Control at AC4.

6. OBSERVATIONS AND CONCLUSIONS

Several observations and conclusions may be drawn from the results obtained during ground and flight tests of three single engine propeller driven General Aviation aircraft:

1. The Conditioned Response Analysis (CRA) conducted on the Model 182E aircraft clearly demonstrated that a fundamental source associated with the propeller was not included in the set of simulation vectors used in the CRA evaluation. The missing source is believed to be the propeller wake vortex impingement on the fuselage.

2. In-flight linear array measurements recorded on two of the test aircraft clearly showed the cabin acoustic environment to be comprised of traveling waves for several of the fundamental tones in the spectra. This being the case, local control of the source(s) in the forward cabin should potentially provide global control within the cabin; however, this was not the case. It is believed that there must be a noise source being convected along the cabin, reinforcing the cabin sound field. Propeller wake vortex impingement may be the convected source.

3. In addition to exhaust impingement as a source of cabin noise, under cowling engine case radiation appears to be a contributing source, particularly in the mid frequency region (500 Hz).

4. Structure-borne noise transmission from engine vibration does not appear to be a major source of cabin noise for the truss type engine mount configuration found on the Model 182 aircraft tested. Some indication of potential structure-borne noise transmission in the higher frequency region was found on the Model 206 aircraft, which uses a light weight frame type bed mount structure.

5. In general, only small noise control gains can be accomplished by treating selected areas of the cabin fuselage independently. However, from the surface treatments evaluated, it was determined that treating the windshield and forward cabin windows with increased mass loading or damping treatments appeared to have good potential for cabin noise reduction. Time and resources did not allow further evaluation of this potential passive control measure.

6. Under cowling treatment consisting of firewall mass loading, cowling absorption, and muffler isolation was a viable low frequency noise control treatment for the forward cabin of the aircraft.

7. Treatment of the fuselage tail cone volume and the rather flexible bulkhead separating the aft cabin from the tail cone provided little or no influence on cabin noise levels during flight. These results support the traveling wave environment found with the linear array measurements.

8. Measurable overall noise reduction was achieved at several engine power and speed points when replacing the standard two-bladed propeller with a three-bladed propeller on the Model 182 aircraft. The noise reductions are believed to be due to the reduced per blade loading. The coincidence of the fundamental propeller and exhaust tones when using the three-bladed propeller significantly reduced the number of offending tones in the cabin spectra, which was advantageous when implementing an active noise control system for the aircraft.

9. The standard Model 182 interior provided nearly 4 dB overall cabin noise reduction. Surprisingly, benefits were found at the 120 Hz tone and, as expected, in the higher frequencies of the spectrum.

10. Distributed Vibration Absorbers (DVAs) were attached to nearly all exposed structural panels within the cabin (42 DVAs in all) targeting control of the 120 Hz and 240 Hz tones. Through the use of equivalent masses to those of the DVAs, it was found that the DVAs provided more of a blocking mass effect than that of energy absorption.

11. Active Structural Acoustic Control (ASAC) using 8 Motran exciters on the cabin structure provided 6 to 12 dBA noise control at the 120 Hz tone in the forward cabin, and when combined with the firewall and DVA treatments, the control increased from 8 to 15 dBA. However, due to high frequency spillover, only 3 dBA overall control was achieved in the frequency range out to 1,000 Hz.

12. It appears the combination of passive and active treatments for low frequency noise control and standard interior for high frequency control may provide the optimum control measure for the single engine General Aviation aircraft.

7. REFERENCES

NASA General Aviation Database

	Date	Description	Author	Document	Enclosures
1.	Dec 1999	Source Path Identification Technology	Jim Unruh Paul Till	General Aviation Interior Noise: Part I – Source Path Identification Technology	
2.	June 2000	In-Flight Source Verification	Jim Unruh Paul Till	General Aviation Interior Noise: Part II – In-Flight Source Verification	
3.	Aug 3, 2000	Telecon Notes	Rich Silcox	Telecon Notes	
4.	Aug 18, 2000	Telecon	Rich Silcox	Telecon Notes	Window Accelerometer Cabin Phase Testplan, V2
5.	Aug 30, 2000	Telecon Notes	Dan Palumbo	Telecon Notes	
6.	Aug 30, 2000	Speaker Locations	Guy Billoud	Guy's Comments	Candidate Speaker Locations.pdf
7.	Aug 30, 2000	Acoustic Modes	Steve Booth	Acoustic Modes	
8.	Aug 30,2000	Test Plan	Jim Unruh	Test Plan	TestPlan3.pdf
9.	Aug 30, 2000	Speaker Locations	Guy Billoud	Discussion	
10.	Sept. 6, 2000	Comment	Chris Fuller	Chris's Comments	
11.	Sept. 7, 2000	Comment	Guy Billoud	Guy's Comments	
12.	Sept. 9, 2000	Telecon Notes	Dan Palumbo	Telecon Notes	
13.	Sept 9, 2000	Comments	Guy Billoud	Guy's Comments	
14.	Sept. 11, 2000	Comments	Ted Farwell	Ted's Comments	
15.	Sept 12, 2000	G/A Noise Schedule	Jim Unruh	Test Schedule.htm	Test Schedule.PDF
16.	Sept. 13, 2000				
17.	Sept. 13, 2000	Tap Test	Ted Farwell	Tap Test.htm	
18.	Sept. 13, 2000	Reference	Ted Farwell	Engine Installation	lh generator.jpg lh Spinner.jpg rh spinner.jpg rh vacuum pump.jpg
19.	Sept. 14, 2000	Reference	Ted Farwell	182E Engine Installation_2	ms3325.pdf an4045.pdf as972.pdf
20.	Sept. 19, 2000	Tap Test Data	Jim Unruh	Tap Test Analysis	taptest.pdf
21.	Sept. 20, 2000	Speaker Spec	Gary Gibbs		Speaker Spec
22.	Sept. 25, 2000	Telecon Notes	Dan Palumbo	Telecon Notes	
23.	Sept. 28, 2000	Junker 182	Rick Wright		Zip File of Jpegs
24.	Sept. 28, 2000	Telecon Notes	Dan Palumbo	Telecon Notes	
25.	Sept. 29, 2000	Vacuum pump	Ted Farwell	Vacuum Pump details	Pic00001.jpg, Pic00002.jpg Pic00003.jpg, PIC00004.JPG Pic00005.jpg, Pic00006.jpg
26.	Oct. 2, 2000	Muffler Benefit	Ted Farwell	Muffler Benefit	
27.	Oct. 4, 2000	Test Plan	Jim Unruh		Test Plan
28.	Oct 5, 2000	Tach Drive	Steve Booth		Picture 1 Picture 2
29.	Oct. 5, 2000	VT test goals	Chris Fuller	Cessna test	
30.	Oct. 10, 2000	Exhaust Extension & Muffler	Ted Farwell	Exhaust Extension	
31.	Oct. 11, 2000	Test Plan	Jim Unruh	GA Noise Test Matrix	Final Test Plan.pdf
32.	Oct 13, 2000	Borla Exhaust Data	Ted Farwell		BORLAREP.pdf
33.	Oct. 26, 2000	Muffler	Ted Farwell	Muffler Again	

	Date	Description	Author	Document	Enclosures
34.	Oct. 26, 2000	Oct. Test Results	Jim Unruh	GA Noise Overall	Overall SPL.pdf
35.	Oct. 31, 2000	Oct. Test Results	Jim Unruh		TailCone
36.	Nov. 3, 2000	Telecon Notes	Dan Palumbo	Telecon Notes	
37.	Nov. 7, 2000	ASAC	Mike Kidner	ASAC performance	ASAC performance.pdf
38.	Nov. 8, 2000	Optical Encoder	Ran Cabell	encoder files	Encoder Data prob.pdf
39.	Nov. 9, 2000	Speaker FRF's	Jim Unruh	GA Noise - ANC	Speaker FRF.pdf
40.	Nov. 9, 2000	Encoder Failure	Ted Farwell	Rotary Encoder	disassembled.jpg
41.	Nov. 13, 2000	Project Status	Dan Palumbo	Project Status	
42.	Nov. 15, 2000	Flight Matrix	SRI		Flight Data
43.	Nov. 15, 2000	ANC FRFs	SRI		FRFs
44.	Nov. 27, 2000	Linear Array	Jim Unruh		Linear Array.pdf
45.	Nov. 28, 2000	High Frequency Tone	Jim Unruh		HighTone.pdf
46.	Nov. 28, 2000	GA ANC Results	Mike Kidner		GA Optimizations.htm GA Opt.pdf
47.	Dec. 5, 2000	FRF Cal Factors	Jim Unruh	FRF Cal Factors.htm	
48.	Dec. 6, 2000	Traveling Wave	Jim Unruh		Traveling Wave.pdf
49.	Dec. 12, 2000	ANC Constrained	Mike Kidner		ANC Constrained.pdf
50.	Dec. 13, 2000	Magnetic Pickup	Dan Palumbo	Mag PickUp Reference.htm	MagPickupRef.pdf
51.	Dec. 19, 2000	Telecon Summary	Dan Palumbo	telecon summary.htm	
52.	Jan. 8, 2001	Happy New Year	Jim Unruh	GA - Noise.htm	
53.	Jan. 9, 2001	Improved ANC results	Mike Kidner	ANC results.htm	ANC Simulation.pdf
54.	Jan. 10, 2001	Call for Telecon	Dan Palumbo	Telecon Thursday Jan 11.htm	
55.	Jan. 11, 2001	Telecon Summary	Dan Palumbo	Jan 11 Telecon Summary.htm	
56.	Jan. 15, 2001	ANC Coherence	Mike Kidner		ANC Coherence Limited.PDF
57.	Jan. 19, 2001	Telecon Summary	Dan Palumbo	Jan 18 Telecon Summary .htm	
58.	Jan. 24, 2001	Firewall Treatment & Test Schedule	Jim Unruh		FirewallTreatmentv2.pdf MarchTestScheduleRev0.pdf
59.	Jan. 24, 2001	ANC Coherence Narrow Band	Mike Kidner		Coherence Limt Narrow Band.pdf
60.	Jan. 24, 2001	Windshield Treatment	Grant Nash (VT)		Windshield.pdf
61.	Jan. 25, 2001	VT Test Schedule	Rick Wright		VT Test Schedule.pdf
62.	Jan. 29, 2001	ATVA predictions	Rick Wright	ATVA Update.txt	fb_cont_dsgn.pdf ATVASampleResults.pdf
63.	Feb. 1, 2001	PA-24 testing	Steve Booth		Pa_24.pdf
64.	Feb. 14, 2001	Latest Test Schedule	Jim Unruh		TestSchedule.pdf
65.	Feb. 21, 2001	Flight Test Topics	Jim Unruh		TestSchedulev4.pdf 206EngineMount.pdf OpticalPickupCoherence.pdf
66.	Feb. 28, 2001	New Test Schedule	Jim Unruh		TestScheduleRev3.pdf
67.	Feb. 28, 2001	DVA Characteristics	Mike Kidner		DVA.pdf
68.	March 7, 2001	Constrained Layer Damped Plexiglass	Ralph Buehrle		cld.pdf
69.	March 8, 2001	Foam Evaluation for DVA	Mike Kidner		FoamEvaluation.pdf
70.	March 13, 2001	March Test Schedule	Jim Unruh		SwRIScheduleRev5.pdf
71.	March 14, 2001	VT 152 Test Schedule	Mike Kidner		VTschedule.pdf
72.	March 14, 2001	ATVA 152 Test Schedule	Rick Wright		ATVAschedule.pdf
73.	March 15, 2001	Window Panel Shaker	Ralph Buehrle		ThinPanel.pdf

	Date	Description	Author	Document	Enclosures
		Tests			ThinPanel4.pdf ThickPanel.pdf ThickPanel4.pdf
74.	April 5, 2001	Baseline 152	Mike Kidner		Baseline152.pdf
75.	April 5, 2001	CDL Radiation Results	Gary Gibbs		125_3rd_oct.pdf 125_radiation.pdf 125to250_radiation.pdf 250_3rd_oct.pdf 250_rad_vs_vel.pdf 250_radiation.pdf
76.	April 11, 2001	Cessna 152 Excitation			152Excitation.pdf
77.	April 25, 2001	Tap Test Data	Jim Unruh		tt206a.pdf
78.	April 25, 2001	Linear Array Results	Jim Unruh		LinearArray.pdf
79.	May 1, 2001	Photos of 206	Jim Unruh		206 Photos
80.	May 1, 2001	206 Tap Test Data	Jim Unruh		206TapTest
81.	May 6, 2001	206 Flight Test Data	Jim Unruh		Observations.pdf 206march.pdf
82.	May 23, 2001	Tone Phase Evaluation	Jim Unruh		tonephase.pdf
83.	May 24, 2001	Test Plan	Mike Kidner		Tech test plan requests.txt
84.	May 24, 2001	Flight Test Status	Dan Palumbo		Noise Control Flight Test Status.txt
85.	June 4, 2001	Time Data, Microphones and Optical Pickup	Jim Unruh	206 Time History Data.txt	optical.xls , time_data.zip
86.	June 21, 2001	Test Schedule			1st week of 206 proj.txt GA206 Flight Test 4.txt July Strawman Schedule
87.	June 21, 2001	152 ASAC Tests	Kidner		Preliminary ASAC tests on 152 fuselage at VTech
88.	June 28, 2001	Coherence, Noise Reduction & Signal to Noise Ratio	Palumbo		nr2snr.pdf
89.	Sept. 20, 2001	Weights of Standard Trim and DVAs	Unruh		trim-weights.xls
90.	Sept. 20, 2001	Passive Treatment Evaluation	Unruh		Passive
91.	Sept. 20, 2001	Individual Treatment Analyses	Unruh		Standard Trim No Trim Firewall Only DVA Run #1 DVA Run #2 DVA + Side Window 'Special Divas' DVA Equiv Mass
92.	Sept. 20, 2001	ASAC Analyses	Unruh		6 ac + 7 er 6 ac + 8 er 8 ac + 8 er
93.	Sept. 20, 2001	ASAC Data	Unruh	These are large Files!!!	ASAC-6ac-7er.xls ASAC-6ac-8er.xls ASAC-8ac-8er.xls
94.	Sept. 20, 2001	Cabin Noise Spectra	Unruh		Full Treatment
95.	Sept. 20, 2001	ASAC Data	Unruh	Comparison of Best Runs	asac-best.xls

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
May 2002

3. REPORT TYPE AND DATES COVERED
Contractor Report

4. TITLE AND SUBTITLE
General Aviation Interior Noise: Part III - Noise Control Measure Evaluation

5. FUNDING NUMBERS
NAG1-2288
781-10-13-01

6. AUTHOR(S)
James F. Unruh, and Paul D. Till

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Southwest Research Institute
San Antonio, Texas

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23681-2199

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CR-2002-211667

11. SUPPLEMENTARY NOTES
Langley Technical Monitor: Daniel L. Palumbo

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 03 Distribution: Nonstandard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The work reported herein is an extension to the work accomplished under NASA Grant NAG1-2091 on the development of noise/source/path identification techniques for single engine propeller driven General Aviation aircraft. The previous work developed a Conditioned Response Analysis (CRA) technique to identify potential noise sources that contributed to the dominating tonal responses within the aircraft cabin. The objective of the present effort was to improve and verify the findings of the CRA and develop and demonstrate noise control measures for single engine propeller driven General Aviation aircraft.

14. SUBJECT TERMS
Noise Source/Path Identification, General Aviation Aircraft, Active Structural Acoustic Control, Distributed Vibration Absorbers

15. NUMBER OF PAGES
60

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL